The WELDING JOURNAL

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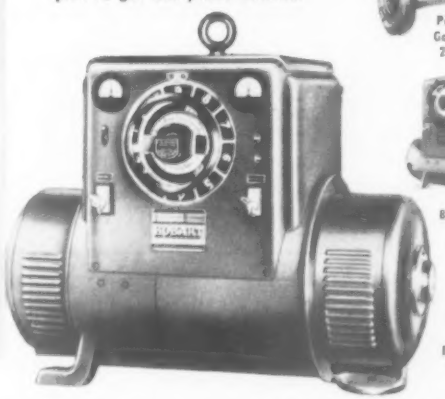

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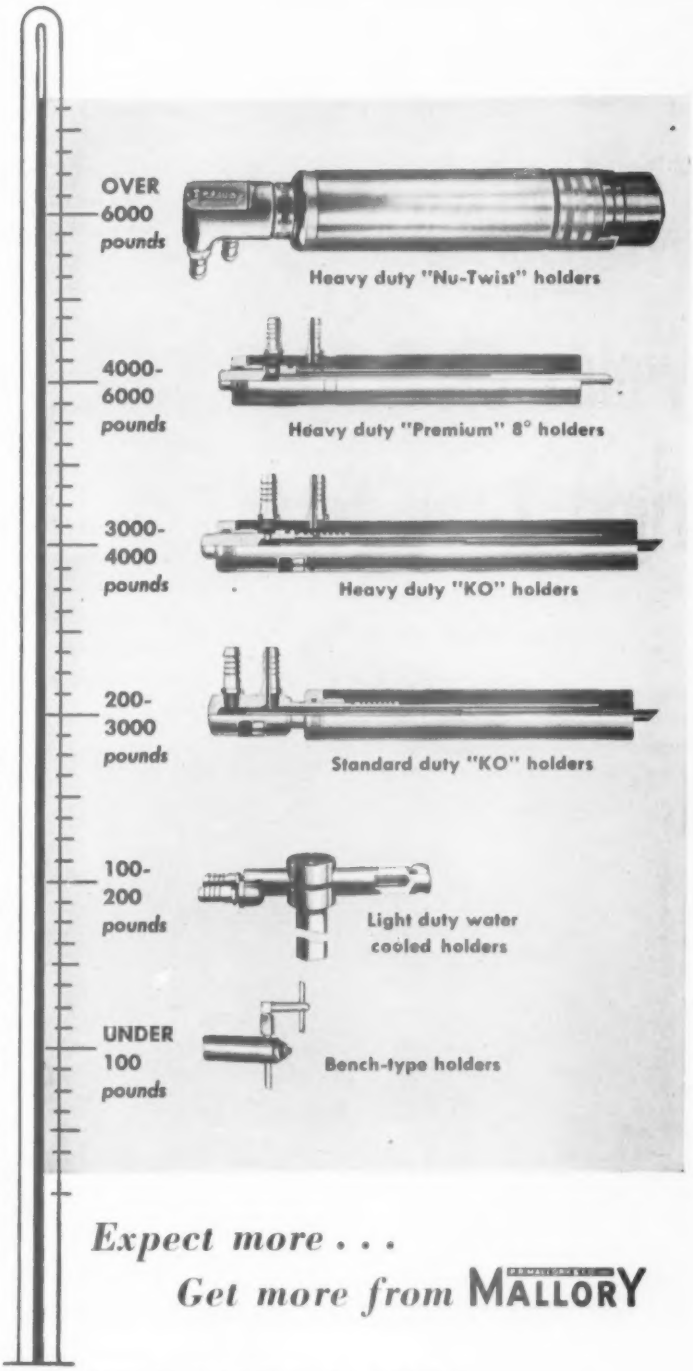

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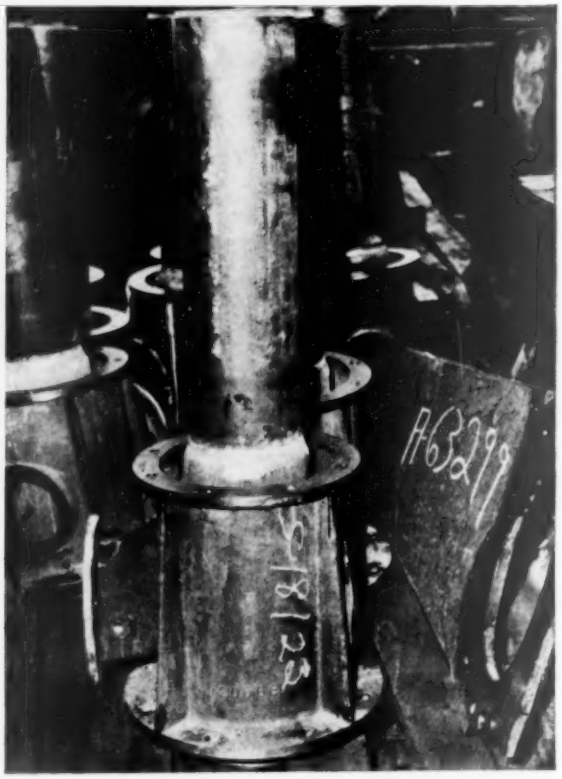

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The WELDING JOURNAL

volume 32 June 1953 number 6

Design of Welded Steel Bridges and Buildings

Advantages of welded construction, steel for welded structures, fabrication procedures, results of research and examples of welded buildings

by F. L. Plummer

FIRST, let us briefly review together some of the oft repeated and almost obvious facts about designs of welded structures.

Consider design in its broad sense and not merely as stress analysis and determination of section areas and shapes.

Service requirements will determine the type, size and shape of the structure, the load conditions whether static or dynamic, temperature variations, and other special factors affecting its required strength.

Comparative studies combined with accumulated experience will indicate the most suitable economic material for the structure. If steel is selected for a given structure we must then decide what method is to be used to join the separate structural elements so as to form the single integral unit. If it is decided to use welded joints, we may normally expect to accomplish the following results in comparison with a design based on the use of riveted or bolted connections:

1. Reduce the size and weight of structural members and their connections. Full areas of tension members and tension flanges of beams and girders are effective, reducing required sections by as much as 15%. Members subjected to bending or combined bending and direct stresses may be designed and simply constructed to take advantage of "continuity." Size of gusset plates, splice plates and other connection details may be materially reduced—some may be completely eliminated. Heights of building will usually be reduced, since floor beams will be of less depth.

2. Eliminate most of the layout, punching, drilling and countersinking of holes, thereby reducing fabricating time and expense.

F. L. Plummer is Director of Engineering at the Hammond Iron Works, Warren, Pa.

This paper is part of the Proceedings of the Second Illinois Structural Engineering Conference.

3. Reduce noise during erection—an important factor at sites in congested areas and when additions are to be made to hospitals, office buildings and other occupied commercial and industrial buildings.

4. Give greater freedom to engineers and architects, making it easier for them to meet service requirements and at the same time design structures pleasing architecturally. Welded structures can readily be made fully continuous to provide resistance to lateral forces of hurricanes, earthquakes, atomic blasts and other emergency conditions, which make it desirable and economical to develop full "limit design" strengths. It is relatively easy to add to or alter welded structures.

5. Produce smooth surfaces which in certain services mean less corrosion, lower painting and maintenance costs. Produce liquid- and vapor-tight containers which require no caulking.

6. Reduce time for preparation of general and detail drawings, time for fabrication and time for erection because of fewer pieces and simpler details.

7. Reduce size and cost of foundations if safe bearing power of soil at site is low.

At the same time we must give more careful attention to: (*a*) The Steel We Use. ASTM A-7 and A-283 are commonly used types. Chemistry (amount of C and Mn) largely determines the physical properties (ultimate tensile strength, yield point, percent elongation and reduction of area) which are commonly reported as the results of tests at room temperature of small bars subjected to longitudinal pulls. The method of finishing the steel—whether rimmed, semikilled or fully killed—will have significant effect upon the ductility and impact strength of the metal at low temperatures. The thickness of steel parts has an important influence on effects created by the heat introduced by fusion welding. In general, the thicker the plate, the steeper the temperature gradient resulting in a thin zone of heat-affected

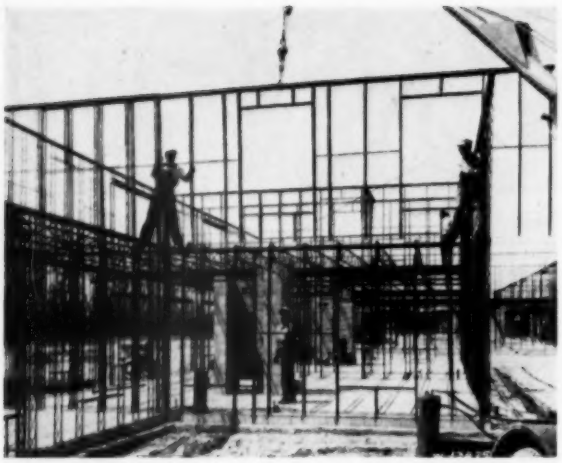

Fig. 1 Placing a second-floor prefabricated wall panel made of 4-in. Bethlehem steel studs in one of the multiple family Estabrook Apartment Projects in Shorewood, Milwaukee, Wis. (Photos supplied through courtesy Lincoln Electric Co.)

Welded construction and unusual erection methods reduced cost 50% on the steel framing compared to regular masonry fire-resistive construction.

Fig. 2 Welding the channel caps of prefabricated sections in the Estabrook Apartment Project. A simple pipe clamp holds channels together for welding

metal, more abrupt changes, more hardening, more residual stress. Thus, it is desirable to keep welded plates thin if possible.

Carbon equivalent is defined as carbon content plus one-sixth of manganese content. For structures such as buildings subjected to essentially static loads, steels with carbon equivalent less than about 0.43, or in thickness up to about 1 1/2 in., may normally be welded by standard procedures with no special precautions. If the carbon equivalent exceeds 0.43 and if the thickness is greater than 1 1/2 in., the use of low-hydrogen type electrodes (E6015 or E6016) at ambient temperature or of the commonly used electrodes (E6010 or E6011) with preheat of 100–150° F should be considered.

For structures such as bridges subjected to dynamic loading, A-7 steels in thickness up to about 1 in. may be welded without special precautions. For greater thicknesses and if the carbon equivalent is greater than about 0.40 similar precautions should be considered.

In order to insure better service properties for welded steel structures, especially at low temperatures and for dynamic type loads some groups (American Bureau of Ships, some highway departments and certain petroleum corporations) are requiring the use of better quality steels for the thicker plates, A-7 or A-283 being used for thicknesses up to 1/2 in. For thicknesses over 1/2 in. and up to 1 in. maximum carbon is limited to 0.23–0.27 and manganese to 0.50–0.90. For thicknesses over 1 in. maximum carbon is limited to 0.25–0.27, manganese to 0.60–1.25, silicon to 0.15–0.30 and fine grained or fully killed finish is required. Note that fully killed steel with lower carbon and slightly increased manganese will be tougher and have better weldability.

(*b*) Design. Methods of analysis and design are essentially the same for welded structures as for riveted or bolted structures. The strength of a fillet weld, regardless of the direction of the force acting upon it, is assumed to equal a basic allowable unit shear stress multiplied by the product of the throat dimension and the effective length (actual minus allowance for end imperfections) of the weld. The allowable unit shear stress is determined by tests which are analyzed in this same manner. Some foreign codes give different allowable shear values for fillet welds which are made longitudinal with or transverse to the primary stress. In this country and for buildings and other structures subjected to static loads no distinction is made. For dynamic loading, stress values may be varied as outlined in AWS specifications for bridges, depending upon the estimated number of stress repetitions during the probable life of the structure. For repeated stress cycles welded butt joints are much more effective than a lap joint with fillet welds or rivets. Design of welded eccentric connections involves no new principles.

It is much simpler to detail welded structures to take advantage of continuity and save material as compared with simple conventional framing, than in riveted construction because stress can be transferred directly by welds. Since welded girders usually have fewer parts and less material than riveted girders, they will often be found economical for longer spans and heavier loads in place of trusses. If architectural requirements for openings indicate the use of a truss, the welded truss will have an important advantage because no gusset plates or only very small ones will be required.

As for all types of structures, details are most important. Too often the main members of structures are carefully designed but connection and other details, whether riveted or welded, are slighted. Welding is an expensive operation. Do not call for extra welding. Do not write "weld "and expect welding operator to de-

Fig. 3 The steel framework for the Long Beach Harbor Shed, Long Beach, Calif., consists of 32 rigid frames each weighing approximately 50 tons and spanning 200 ft.

Frames were shop welded and then positioned at the site for making field splices. After frames and webs were welded on the ground, the frames were hoisted and the welded joint completed in position. The vertical pass in the double bevel 60-deg joint was made with a 3/16-in. E6012 electrode, followed by two passes with a 1/8-in. E6020 electrode. Joint preparation in the 1 1/2-in. thick flanges was a double vee 60-deg bevel with a 1/16-in. land. All welding on flanges was done with a low-hydrogen electrode, L. H. 70.

sign your connections. When preparing details, keep in mind the operator who must do the shop and field welding. Provide adequate edge distance for fillet welds (at least 1/8 in.). Plan for positioned welding in the shop. Avoid overhead field welds. Select shapes and plates and member sections so as to minimize flame cutting and welding. See *Manual of Design for Arc-Welded Steel Structures.*

(*c*) Fabrication. More careful inspection is important. For welded butt joints as compared with riveted lap joints closer tolerances must be held. For maximum economy welding should be downhand. When possible complete symmetrical welds simultaneously so as to balance heat input and minimize distortion. Establish proper weld procedures and be sure they are followed. Use qualified welding operators. Many large structural shops have almost completely standardized riveted construction. Equipment is largely automatic. Cutting and welding equipment is less expensive, more flexible, but the resulting work must be more carefully inspected and checked. Use automatic welding when economical. Restrict bolt holes in heavy beams to web of beam.

(*d*) Erection. The steel erector of a tier type building must plumb his columns, hold them in position and support erection equipment and possibly other loads before the beam and column joints are welded. He must have simple, economical means, such as temporary bolts, for doing this. Shrinkage in welded joints, over- or underrun of structural shapes, and improper shop fabrication tolerances can create major difficulties in securing a properly aligned building. A butt joint may shrink about 1/8 in. Thus five panels of beams set between a series of six columns and butt welded to these columns with ten butt welds might have a cumulative shrinkage of 1 1/4 in. If the beams were welded to the flanges of succeeding columns and all the column section depths were less than normal, this figure would be increased. If the beams were all fabricated within shop tolerance but slightly short, the situation would be even worse. The steel erector must, therefore, carefully plan his erection procedure, "pack out" and spread the steel as assembled to provide for these factors. If masonry walls and framing for openings are to be supported on spandrel angles, there should be provision for adjusting the location of such angles. All overhead field welding should be eliminated if possible.

Some erectors favor columns with milled ends to avoid possible accumulated error due to distortion of end plates used with fillet welds on top. Use fillet welded angles rather than butt weld beam web to column, in order to provide some adjustment.

Several non-destructive methods of weld inspection have been developed. Low-cost, portable, X-ray equipment is available and being used by fabricators of field-erected storage and process vessels. Several firms offer complete testing services. For buildings and similar structures the added cost of such inspection does not seem to be justified if proper weld procedures are established and

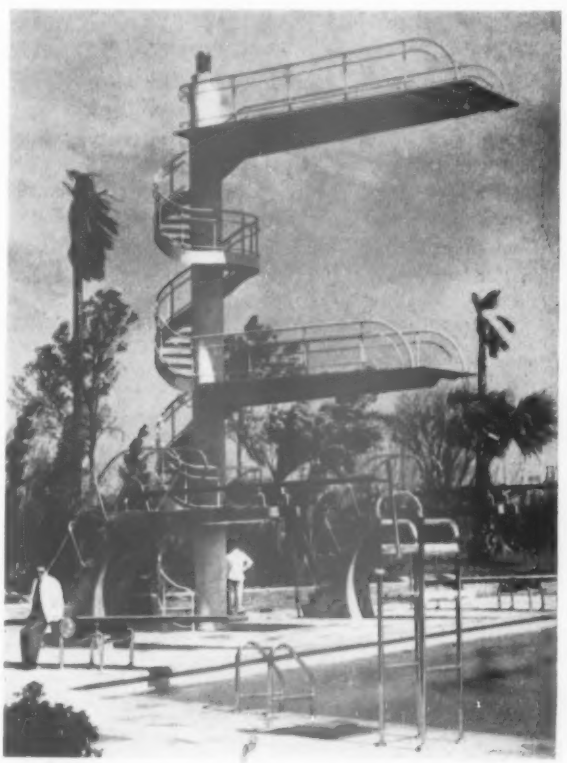

Fig. 4 The graceful appearance of this 10-meter diving tower at the Shamrock Hotel in Houston, Tex., results from the extensive use of welded tubular material in the design

The shaft is a 24-in. diam, 1/2-in. wall steel pipe with a 1-in. × 2-ft 6-in. bolt length at the base. It is 37 ft, 8 1/2 in. high. Cantilever platform supports are channels split and tapered.

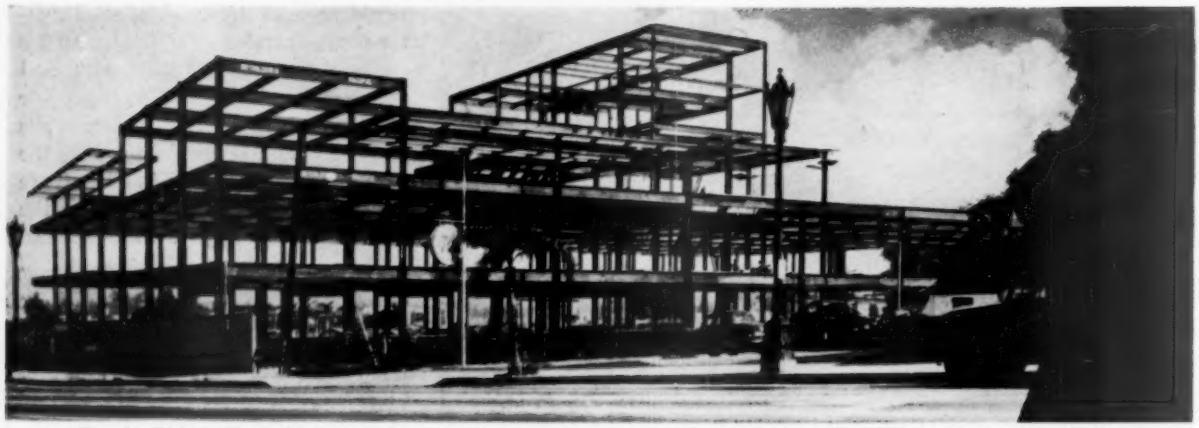

Fig. 5 This is the welded structural steel frame of Robinson Beverly Department Store, Beverly Hills, Calif.

It is a four-story structure with 244,000 sq ft of floor area. A saving in steel tonnage of 15% was made possible by welded design. The design featured unusual column and girder treatment to provide full vertical and horizontal continuity.

followed by qualified welding operators. Normal inspection can and should insure this result.

Research Projects. Many important research projects have been started during the past ten years. Some are still in progress. All have yielded significant and useful information. The following are included:

1. Column Research Council. Organized in 1944. Still active. Programs at University of Washington, Aluminum Co., Lehigh University, Brown University, University of Illinois, Penn State College. Major studies include: (*a*) Basic column formula, (*b*) end milling tolerances, (*c*) local buckling, (*d*) members of frames and trusses, (*e*) combined direct stress and bending, (*f*) dynamic loading, (*g*) top chords of bridges with no lateral bracing.

2. Fatigue Tests of Beams in Flexure. Welding Research Council, University of Illinois, Professor Wilson, Bulletins 377 and 382. Twenty-seven beam types, 104 specimens. Fatigue strength at 100,000 and 2,000,000 cycles. Test results indicate:

(*a*) Carrying capacity of rolled beams greater than that of fabricated beams for same section modulus.

(*b*) Carrying capacity of beam with cover plates cannot be increased indefinitely by increasing "*t*."

(*c*) Cover plates should be full length or so "*f*" at end of plate is not more than 40% of "*f*" at center of beam.

(*d*) Weld across end of cover plates about same as along sides.

(*e*) Continuous fillet weld better than intermittent weld or rivets.

(*f*) Capacity of beam reduced if stiffeners or lateral plates are welded to tension flange.

(*g*) Cannot splice beam by butt weld or riveting to equal rolled beam.

(*h*) Fatigue failures will not occur in long-span girders since 100,000 cycle "*f*" is high.

3. Impact and Static Test of Butt-Welded Beams. Welding Research Council, Columbia University;

Fig. 6 Welding of a typical column joint to develop continuity in both directions

Girders are run through the column with top and base welded to girder flange. Vertical stiffeners shop welded to girder webs provide continuity; top plate with slot to provide extra weld area to develop continuity across transverse beam.

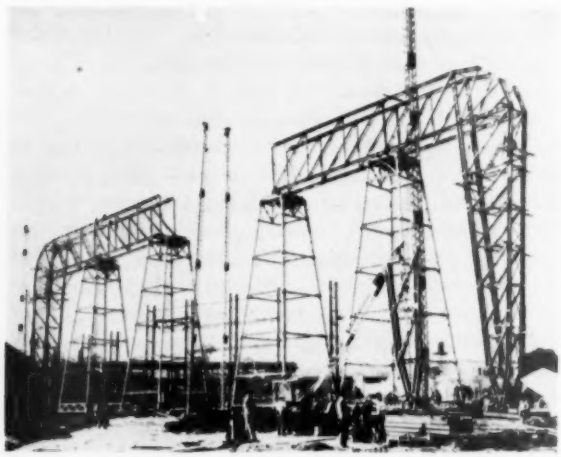

Fig. 7 This is said to be the world's largest welded rigid frame

The frame spans 328 ft and is one of nine similar frames which comprise the steel framework of a municipal auditorium in Mexico City. It is claimed that a weight saving of 50% was achieved by design of welded construction. Lightness was essential because of the sandy subsoil conditions. The framework used 6000 tons of structural steel.

Fig. 8 This is one of the country's tallest welded structures. It is the 21-story City National Bank Building in Houston, Tex.

16-in. WF 70-lb. beams—100 of fully killed steel and 50 of semikilled steel were tested on a 12-ft span, in unwelded or as-welded with and without preheat or postheat conditions, and at both room and low temperatures. Residual stresses were measured by trepanned samples. Under static loads even at low temperature (−115° F) normal failures occurred. Under low temperature and impact loads, brittle fracture may occur. Fully killed steel is better than semikilled steel. Preheat gave better results than postheat.

4. Elastic Stability and Load Carrying Capacity of Struts and Flexural Members. Welding Research Council, Massachusetts Institute of Technology. Includes study of spacing of intermittent welds and buckling of long rectangular plates compressed on the ends and supported on the long sides. Present specifications which provide for gap of 16t are conservative.

5. Ultimate Strength of Continuous Frames. Welding Research Council, Lehigh University. Study of the behavior of beams, columns, connections and rigid frame structures through elastic and into plastic ranges. Develop basis for "plastic or limit design." Major investigations cover: (*a*) collapse loads of columns with axial force and end bending moment; (*b*) effect of residual stress, stress concentration, local buckling and strain hardening on behavior of continuous beams; (*c*) strength, rigidity and economy of various welded connections for rigid frames and for tier buildings; (*d*) behavior of actual rigid frames.

6. Box Girder Investigations. Welding Research Council, National Bureau of Standards. Heavy box girders of poor design with heavy diaphragms extended into tension side corners, and with over heavy welds made by following a welding sequence planned to create reaction type stresses were constructed of semi- and fully killed A-7 steel. Girders were tested at 80, 40, 0 and −40° F as simple beams. Residual stresses were measured. Test results indicate that: (*a*) residual stresses, even at low temperature and in highly restrained heavy structural member, do not destroy useful carrying capacity of member; (*b*) poor weld sequence can cause cracking—proper weld sequence will prevent formation of cracks; (*c*) semikilled steel is not as foolproof as fully killed steel; (*d*) for rigid monolithic structure at low temperatures we should use extra pre-

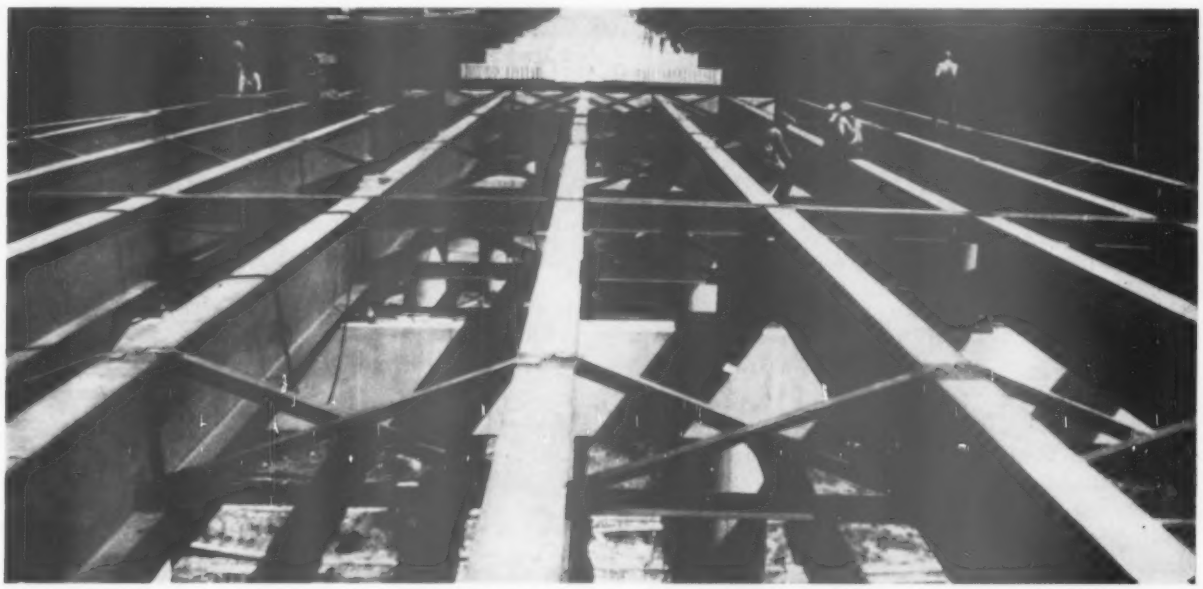

Fig. 9 An all-welded highway bridge near Beaumont, Tex.

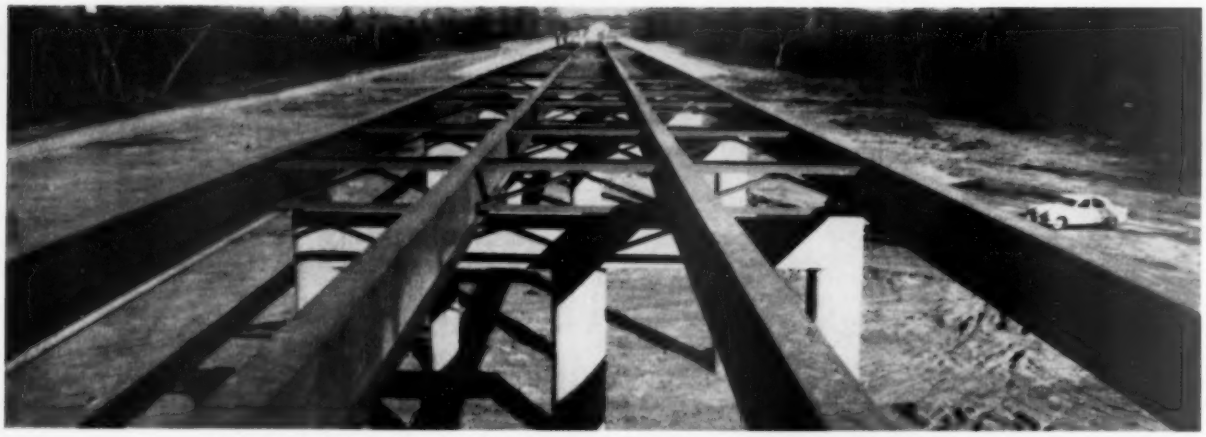

Fig. 10 Another all-welded bridge on the Texas Freeway near Rt. 12, Dallas, Tex.

cautions in design, workmanship and materials; (*e*) laboratory tests cannot now be correlated with actual structures but will give comparative rating of steels.

Now let us quickly review a number of welded structures and note some of the typical details, construction procedures and the resulting savings in weight and cost.

Beam connections may be flexible, partially restrained or fully restrained. Column splices are usually located at a convenient working height above floor levels. The column ends may be milled and joined with butt welds or a butt plate with fillet welds may be used. The two flanges should be welded simultaneously in order to avoid a tendency to pull the column out of plumb. The *Manual of Design for Arc Welded Steel Structures* gives details and strength tables for many types of welded connections. The new edition of the *AISC Manual for Steel Construction* will give similar data. A. E. Pearson of the Ingalls Iron Works Co., in a paper presented at the 1952 Annual Meeting of the AMERICAN WELDING SOCIETY has given detailed cost comparisons for riveted and welded joints and splices of many types.

WELDED BUILDINGS

J. B. McCormick[1] has described the design and construction of an all-welded steel frame building for the Associated Telephone Co. at Laguna Beach, Calif. The building was designed by Maurice Sasso to resist earthquake loading. Competitive bids for riveted and welded designs indicated a saving of 25.7% on tonnage and of 18.7% on cost for the welded steel frame. There was additional savings in foundations, walls and ducts because of lighter weight and less height. Open columns made up of four corner angles with batten plates, lattice bars or solid plates permitted beams and girders to pass continuous through the centers of the columns. Cover plates were used at the columns to produce haunched girders. Because of fewer connections, the general use of downhand welding and no need for scaffolds, the erector reported that he could erect twice as many tons of steel per day and complete the welded joints in 52% of the time required for riveted work.

Buildings for the Bell Telephone Co. at Richmond, Va., and for the Baltimore Sun at Baltimore, Md., are typical of those assembled by the use of special erection seats developed by Van Rensselaer P. Saxe.[2] In the Telephone Building very heavy rolled and built-up column sections involving material thicknesses of the order of 3 in. were used. The Baltimore Sun Building required the use of 1700 tons of steel. Competitive

Fig. 11 This ore bridge made by Heyl & Patterson represents an advancement in ore bridge construction

The span is considered to be 50% welded and is the first ore bridge in which welding has been used for the span. Highly stressed joints in the cross-frames of the span were shop welded and field erected by riveting.

Fig. 12 A section of the new all-welded San Francisco Viaduct. Welding saved 20% in steel requirements. The $15,000,000 project will require approximately 4800 tons of steel

bids showed a saving of 7% for the welded design.

For Robinson's Department Store at Beverly Hills, Calif., the welded steel frame, weighing 1700 tons, cost 15% less than an equivalent riveted frame. The main girders are continuous at the columns which are welded to the top and bottom flanges of the girders, heavy stiffeners having been welded to the girder webs in the shop. Cross beams are also made fully continuous at the columns, the heavy top splice plate being slotted to provide for welding. Use of welded construction made possible a decrease in building height of 6 in. per story.

During the past few years 15 all-welded commercial buildings varying in height from 8 to 24 stories have been constructed in Houston, Tex. No important riveted buildings have been constructed in this area during the last ten years. This unusual record is the result of several favorable factors including: (*a*) a modern, up-to-date building code, (*b*) engineers and architects of vision who have trained themselves to prepare economical designs for welded construction, (*c*) steel fabricators and erectors with equipment, operators and experience such that they welcome inquiries covering welded construction and can plan and complete their work in accordance with a fast, economical schedule and (*d*) competent and experienced inspection services.

Boyd Meyer,[3] Consulting Engineer of Houston, has suggested a welding sequence for tier building floors which may result in 30 to 40% of the floor load being carried by the field welding shrinkage stresses. He suggests that for an entire floor, working out from the center, welding of floor beams proceed as follows: (1) the upper 6 in. of the web shear welds, (2) upper flanges and (3) lower flanges. The tension stresses created in the lower flange at the column connections will be opposite in character to the compression stresses which result from the negative moments created at these sections by the floor loads. Mr. Meyer has also discussed the potential savings which result when metal floors of the cellular type are used reducing floor loads by from 25 to 35 psf and providing greater flexibility in installing electrical and other conduits. Less steel will be required, foundations will be more economical and as much as 3 to 5 months in erection time may be saved thus producing additional rental return. H. F. Crick[3] of Mosher Steel Co. has described the development of welding procedures for fabricating very heavy built-up welded columns with plug and slot welds.

For a new addition to the Mount Sinai Hospital in New York City very heavy welded trusses with butt joints were fabricated by the Ingalls Iron Works Co. The New York City Code now permits full allowable base metal stress for butt-welded connections.

For multifamily apartment buildings of Estabrook Homes in Shorewood, Milwaukee, Wis., prefabricated welded steel wall panels reduced the cost 50% as compared to conventional masonry, fire-resistive construction.

The new 18,500 seat municipal auditorium now being completed at Mexico City includes eight rigid frame box trusses varying in length from 295 to 328 ft. These are believed to be the longest span-welded trusses in the world. Because of soil conditions at the site it was essential to construct a building of minimum weight. Engineers report that welded construction resulted in a savings of over 50% in weight as compared to a conventional riveted design.

The 5- and 10-meter diving tower at the Shamrock Hotel in Houston, Tex., designed by Winfield A. McCracken of Paddock Engineering Co., illustrates the versatility of welded construction. The supporting column consists of a tube. The diving platforms are supported on cantilever beams made by splitting 12-in. channels and rewelding so as to taper to 6 in. at the ends. All of the steel was metalized with aluminum.

The Long Beach Harbor Shed at Long Beach, Calif., is 1200 ft long with office space at each end. The roof is supported on 32 welded rigid frames, each weighing about 50 tons and spanning 200 ft. These frames, assembled on the ground as single units and hoisted into position with three cranes, are typical of the great number of continuous welded frames of various types which have been widely used in industrial buildings.

WELDED BRIDGES

Mr. Hardesty and Mr. Webb have referred to the article regarding welded railroad bridges by Mr. Brodie[4] and to the various discussions of this article published in *Civil Engineering*. Welding has been generally used

Fig. 13 A section of the new all-welded San Francisco Viaduct

Fig. 14 A new welded bridge at Cologne, Germany

for maintenance, alteration and strengthening of railroad bridges in this country for many years, however it has not been widely used in the construction of new bridges. In Germany more than 150 welded railway bridges had been constructed prior to 1940. Other European countries had also established similar successful records of welded bridge construction.

The through-type welded truss railroad bridge at Joncherolles near Paris, France, is an excellent example of a properly engineered welded design. The lower chords which resist tension stresses are constructed of flat plates thus producing a flexible member less subject to secondary stresses. Upper chords and web members consist of wide flange beam sections with plates added so as to provide four webs joined by four sets of gusset plates thus avoiding thick steel sections and keeping welds small.

Fifteen years ago your speaker was Chief Design Engineer for the Main Avenue Bridge Projects in Cleveland. These bridges cost about eight million dollars. Welded construction was used for bridge floors, railings, curbs, fascias, light standards, drainage details, expansion joints, bearing rockers and shoes. In addition the construction included two 3-span rigid frame bridges which are believed to be the first welded bridges erected in that area.

Prior to the last world war 20 welded steel bridges of the Vierendeel type had been constructed across the the Albert Canal in Belgium. The one at Haccourt with a span of 285 ft includes 900 tons of steel and is typical of these early welded bridges. A bridge of this same type having a span of 222 ft has recently been constructed at Lanoye over this same canal. Fully killed steel was used and use of run-off plates prevented the formation of craters at the ends of welds. Diaphragms were not welded to tension flanges.

H. M. Hadley[5] has described a highway bridge in Kings County, Washington, which is supported by two 4- by 5.5-ft welded box girders consisting of thin plates with internal braces but with all cross bracing made unnecessary by the torsional rigidity of these girders.

The U. S. Navy has constructed a welded truss launcher bridge at Pasadena, Calif., which is 300 ft long, 35 ft deep and 22 ft wide. Studies indicated that welded construction should be used because of the following factors: (*a*) more usable space, (*b*) less weight, (*c*) save material, (*d*) lower cost, (*e*) greater rigidity, (*f*) smooth surface reduces painting, (*g*) no sharp corners improves safety, (*h*) cleaner, more attractive appearance.

Welded girder bridges are now generally used by most of our state highway departments. More than 36 welded highway bridges have been constructed in Connecticut, more than 15 in Canada. In Florida similar welded continuous girder bridges with spans of 84, 126 and 84 ft have been constructed over the Suwanee and Withlacoochee Rivers at a cost of $220 per foot compared with $350 per foot for construction previously used. Girders for a five-span continuous girder bridge at Iowa City were fabricated with automatic welding equipment.

L. C. Hollister[6] has discussed the savings and advantages of welded construction for San Francisco's fifteen-million-dollar freeway project. Total steel saved will be 300 to 400 tons representing 20% for girders, 12 to 15 % for columns and 20 to 24% for the bent caps. For steel thicker than $1^1/_2$ in., fine grain steel with limits on C and Mn content was specified.

At Cologne, Germany, a new welded bridge has recently been completed to replace one destroyed during the war. The new bridge with greater capacity required 30% less steel. The three spans of 404, 605 and 407 ft are carried on continuous box girders of very pleasing appearance.

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1952 Adams Lecture

On the Welding of Titanium Alloys

Properties, potentialities and welding characteristics of titanium with a description of applicable processes

by C. B. Voldrich

INTRODUCTION

AT THIS meeting, we again honor Dr. Comfort Avery Adams, in recognition of his long years of fruitful work and leadership in the welding industry. His guidance and teachings in research are known to many of us, and we follow these teachings in the exploration of new fields of welding.

I appreciate the honor and privilege of presenting the tenth Adams Lecture, and the opportunity to give you the story of progress in one of these new fields—the welding of titanium—which is of such increasing importance to all of us.

At the outset, I wish to express my appreciation to the United States Air Force, the Army Ordnance Corps, the Navy Bureau of Aeronautics, Rem-Cru Titanium, Inc., and Battelle Memorial Institute for their permission to use the results of recent research. I also wish to thank the many people in various factories and laboratories who gave me so generously of their time and data on titanium-fabrication problems. In particular, I am grateful to my colleagues at Battelle for their assistance and guidance in the preparation of this lecture.

Titanium is an abundant metal, widely distributed in various parts of the world. Its ores are relatively easy to get at, but the extraction of the metal from the ore, on a truly economical basis, is one of the chief problems in the titanium industry. Indeed, this is the true significance of the word "titanium"—for we are told that Klaproth, who rediscovered titanium in 1797, named it so not because he knew what its strength was, but in recognition of its titanic chemical affinity for the other elements, chiefly oxygen, which make up its ores.

Titanium has several properties which make it an engineering metal of great promise, and a potential competitor of steel, aluminum, magnesium, and other metals. These properties and potentialities have been amply described in many articles, and therefore I shall only summarize on these points before we proceed with the important topic of welding characteristics.

PROPERTIES AND USES OF TITANIUM

Titanium and its alloys are as strong as many of our alloy steels, and are 30 to 40% lighter than steel. Titanium alloys retain useful strength at temperatures up to 800 or 900° F. They have remarkable corrosion resistance to many chemicals and conditions of exposure. These properties, and some others, make titanium and its alloys extremely attractive to the designers of aircraft structures, jet engines, turbines, ordnance materiel and chemical equipment. Titanium and several of its alloys are now produced commercially in various marketable sizes and shapes.

Beyond the above uses, now primarily in military fields, are potential applications in commercial aircraft, in seagoing equipment, in the automotive and railroad industries, and in petroleum and other chemical industries. Many of these applications will, of course, not be practicable until the price of titanium is much lower than it is today—but it is highly significant that engineers and metallurgists in these industries already have titanium-alloy designs on the board, and ready to go when the price is lower and the metal becomes more available.

In the manufacture of titanium structures and equipment, present and future, welding takes an important position. Even now, titanium-metal weldments are in experimental production for aircraft, ordnance and chemical engineering applications, and the use of the stronger titanium alloys for welded structures is under intensive research and development, as for example in compressor casings for jet engines, and in aircraft landing gear.

At present, most weldments are made with commercially pure titanium. This is titanium with no alloy content except small amounts of oxygen, nitrogen, and

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other impurities which are retained or picked up during the processing of the metal from the ore to the sheet, plate, bar or other form. These impurities are actually very beneficial, if they are kept at low levels, because they increase the strength of the titanium and make it much more useful in structural applications.

There are several varieties of commercially pure titanium on the market. The principal difference among them is the amount of residual oxygen and nitrogen, and the resulting difference in strength and ductility. The tensile strength range is about 60–90,000 psi; the yield strength, 50–70,000 psi; and the elongation or ductility, 30% down to 15% (Fig. 1).

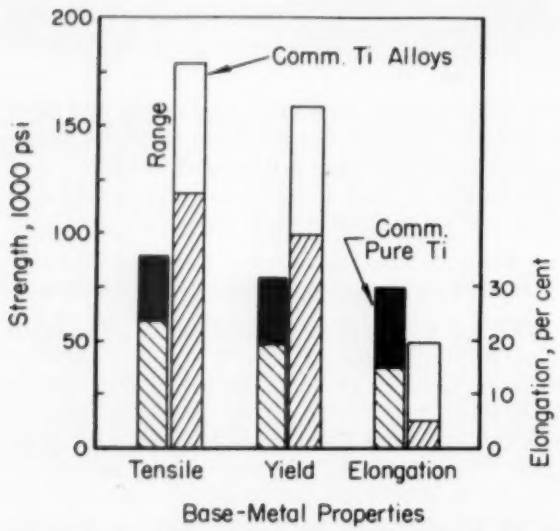


Fig. 1 Strength and ductility of commercially pure titanium and commercial titanium alloys

Commercially pure titanium has very good weldability. With proper attention to the basic welding rules, welded joints in this grade of titanium have strength and ductility almost as good as the unwelded metal (Fig. 2).

A number of high-strength titanium alloys have also been available commercially for some time, and are being tried in many welding applications. These alloys, in which the residual oxygen and nitrogen content is fortified by the addition of other alloying elements, are much stronger than commercially pure titanium (Fig. 1).

The commercial titanium alloys have a tensile strength range of about 120–180,000 psi; a yield strength of about 100–160,000 psi; and an elongation of about 20% down to 5%.

Unfortunately, the high-strength alloys—all of which are now in the so-called alpha-beta class—have one deficiency, so far as welding is concerned. The welds are easily made, and their tensile strength is good, but the metallurgical behavior of many of the alpha-beta alloys causes the welds, and the heat-affected metal next to the welds, to be brittle (Fig. 3).

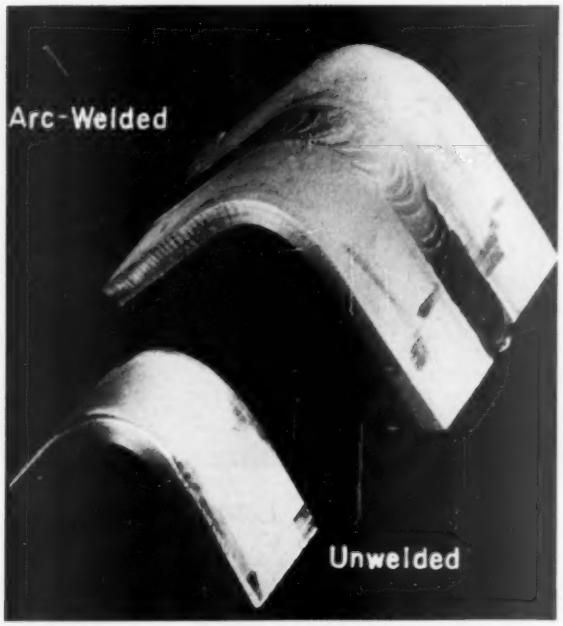


Fig. 2 Bend specimens of welded and unwelded 1/4-in. plates of commercially pure titanium

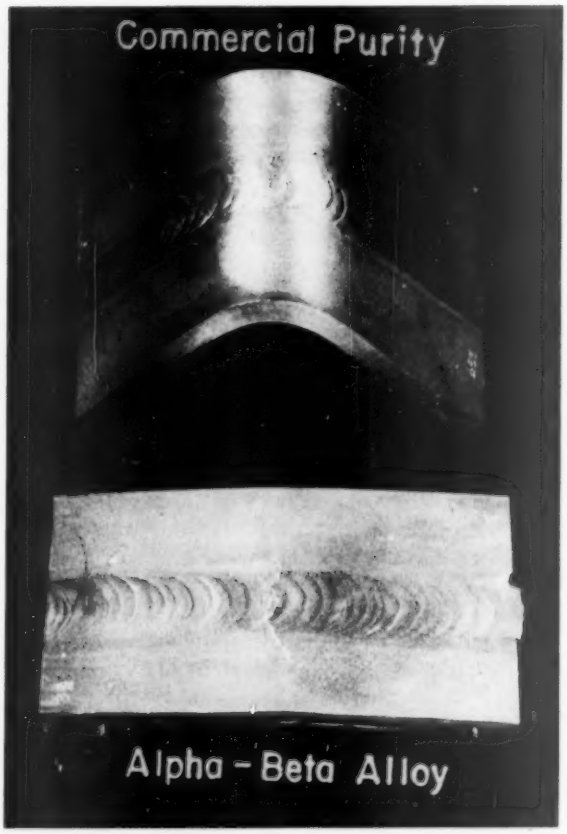


Fig. 3 Comparative bend ductility of welded 1/4-in. plates of commercially pure titanium and a high-strength alpha-beta titanium alloy

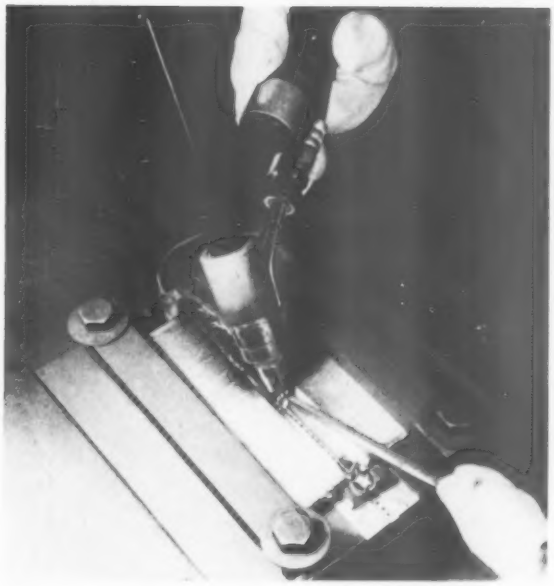
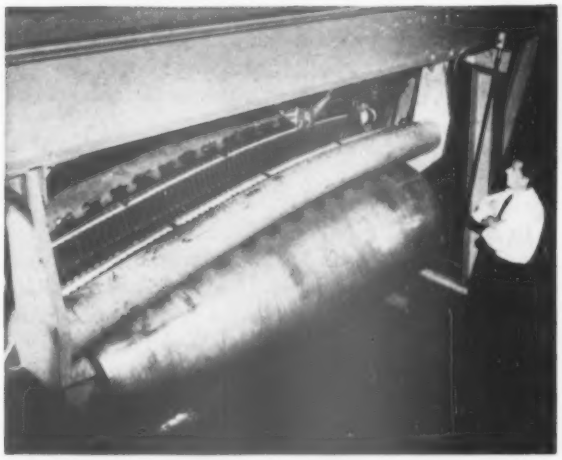


Fig. 4 Inert-gas-shielded tungsten-arc welding of butt joint in titanium plate



Courtesy Rohr Aircraft Co.

Fig. 5 Jig for mechanized tungsten-arc welding of cylindrical assemblies

This, then, is one of the principal problems now under investigation by metallurgists and welding engineers—to develop welding and postheating procedures for making ductile welds in the high-strength titanium alloys; and to develop new alloys which will be strong, without too much sacrifice in weld ductility.

WELDING PROCESSES FOR TITANIUM

Before we proceed with the metallurgical story, let us look at the processes which are being used for the welding of titanium.

Inert-Gas-Shielded Arc Welding

From the research projects at Battelle and other laboratories, it has become evident that among the fusion-welding processes, the best one is inert-gas-shielded arc welding. Because titanium reacts so readily with most elements and compounds, processes such as gas welding, and arc welding with covered electrodes, the atomic-hydrogen torch, or under flux, are not practicable. Inert-gas-shielded arc welding provides the best, and perhaps the only means, of shielding the weld from air—that is, from oxygen and nitrogen pickup which make the weld joint hard and brittle.

For either manual or mechanized inert-gas tungsten-arc welding (Fig. 4), as well as for inert-gas consumable-electrode welding, several conditions are essential for the making of a sound, strong and ductile weld joint. First, the titanium alloy being welded must be inherently ductile, and of a composition which will not cause weld brittleness. This is true for all the welding processes, and is a subject that will be discussed later on.

Second, the surfaces to be welded, and the filler rod, if used, must be clean and free from scale which may have formed during prior hot-working operations.

Third, the molten weld-metal pool and the adjacent heated metal must have a reasonably complete and continuous cover of inert gas.

Fourth, the back of the joint must be protected from air by a backing bar, an auxiliary gas shield, or by a combination of the two.

Courtesy Solar Aircraft Co.

Fig. 6 Welded and flanged ring of commercially pure titanium

Fifth, the shielding gas, which may be either argon, helium, or a mixture of argon and helium, must be of high purity—that is, virtually free from impurities such as nitrogen, oxygen, water vapor and hydrocarbon gases.

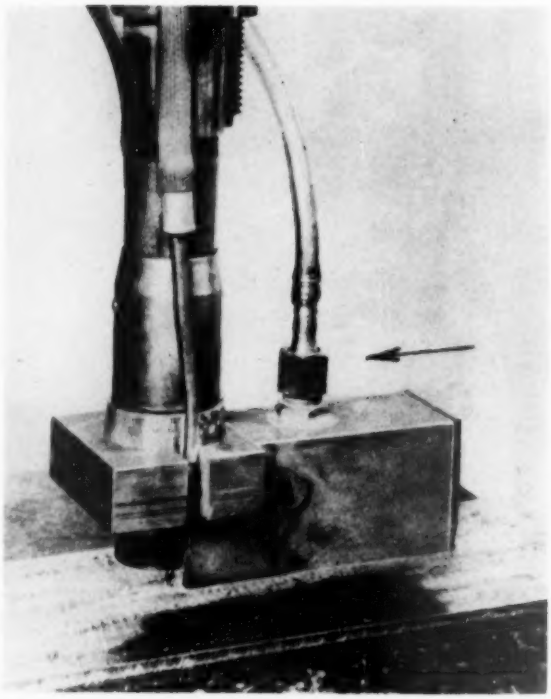
Thus far, the best results with tungsten-arc welding have been obtained using direct current, with the electrode polarity negative.

In mechanized tungsten-arc welding, similar precautions must be taken, and jigs for large aluminum and stainless steel weldments have been adapted for titanium work. Figure 5 shows such a jig at the Rohr Aircraft Co. In this jig, provisions have been made for shielding the back of the weld joint by means of a perforated backing bar, through which an argon-helium mixture is blown to shield the back of the weld.

Under such conditions, production weldments are now being made in commercially pure titanium. Figure 6 shows a typical example—a welded and flanged titanium ring made at the Solar Aircraft Co. The ring was first welded as a cylinder with a longitudinal joint, and then spun hot to the finished form.

The inert-gas-shielded consumable-electrode process, also known as Aircomatic or sigma welding, promises to be very useful for titanium (Fig. 7). The mechanized torch, especially, should facilitate the welding of thicker sections. In this process, the speed of welding is fast, the penetration deep and the weld-metal pool is relatively large and agitated. Consequently, it may be necessary to provide extra-efficient gas shielding, by means of an apron attached to the torch as shown in Fig. 8, with or without auxiliary gas flow, to follow the arc and protect the weld-metal pool. For the consumable-electrode process, the best welding is done using direct current, with the electrode positive.

In experimental welding work, it is often necessary to maintain very close control of shielding conditions, and we have found the closed welding chamber quite useful. Figure 9 shows a rigid type of chamber, into



Courtesy Air Reduction Co., Inc.

Fig. 8 Apron for after-shielding of weld joint (arrow shows direction of torch travel)

which the necessary equipment and material are placed, the chamber closed and evacuated, and then filled with inert gas. The welding can be either manual or automatic. While especially appropriate for laboratory work, some chambers of this kind are being used in special production applications.

The shielding chamber may also be of a flexible type, such as the rubber-walled cylinder designed at the College Park laboratory of the Bureau of Mines (Fig.

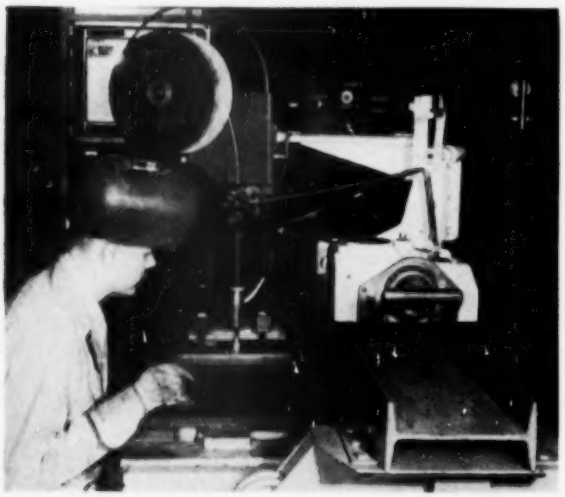


Fig. 7 Inert-gas-shielded consumable-electrode welding of butt joint in titanium plate

Fig. 9 Steel chamber for inert-gas-shielded arc welding

10). After the welding material has been inserted, this chamber is collapsed like an accordion to drive out the air, and is then blown up with inert gas. The eight hand holes, spaced around the cylinder, give good accessibility to the work.

Courtesy U. S. Bureau of Mines

Fig. 10 Flexible chamber for inert-gas-shielded arc welding

Spot and Seam Welding

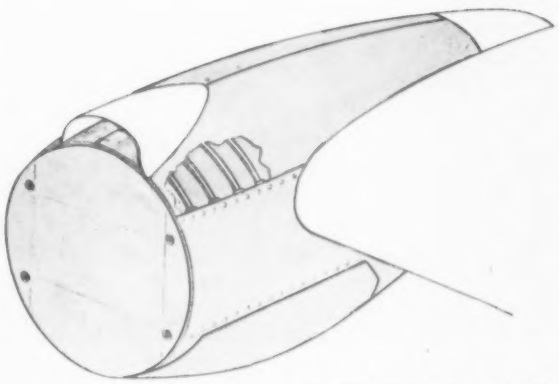
The spot welding of commercially pure titanium presents no particular obstacles, according to all available reports.

Figures 11, 12 and 13 show experimental nacelle and tail-cone structures for Douglas, Boeing and Lockheed aircraft, in which use is made of spot welding, along with riveting and some arc welding, for the assembly of the commercially pure titanium parts. Good spot welds can be made with a wide range of machine settings, and no gas shielding is required. Extensive tests are now in progress in various laboratories, and some data are already available on essential factors such as current density, welding time, pressure, electrode-tip design and the degree of surface cleaning required.

In spot and seam welding, the principal problem is that spot welds in the high-strength alloys generally have a brittle weld and heat-affected zone. So far, none of the usual modifications in welding technique has been effective for the making of ductile spot welds in the alpha-beta alloys.

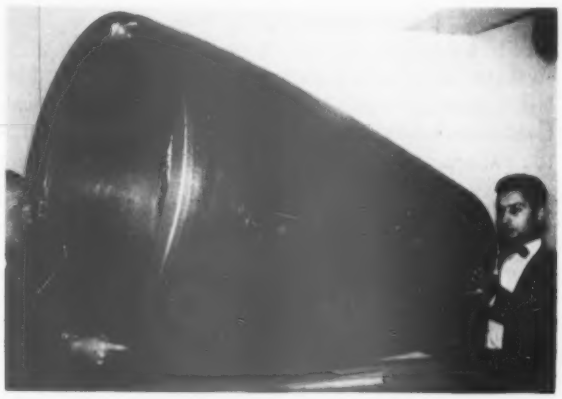
Flash Welding

There have already been several good reports on the flash welding of titanium. I want only to point out



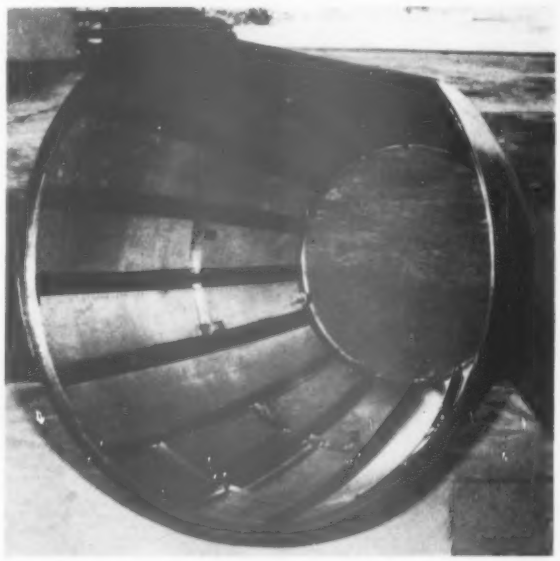
Courtesy Douglas Aircraft Co., Inc.

Fig. 11 Experimental titanium nacelle



Courtesy Boeing Airplane Co.

Fig. 12 Experimental titanium tail-cone assembly



Courtesy Lockheed Aircraft Co.

Fig. 13 Interior view of experimental titanium tail-cone assembly

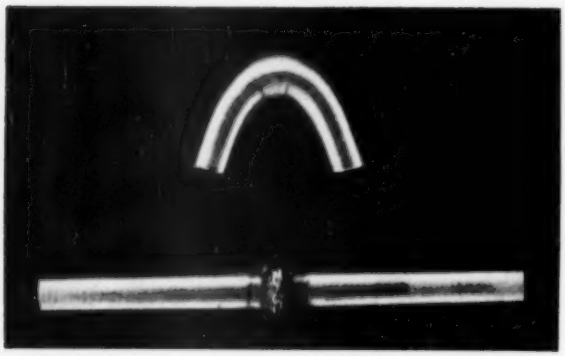


Fig. 14 Flash welds in 1/2-in. round bars of commercially pure titanium

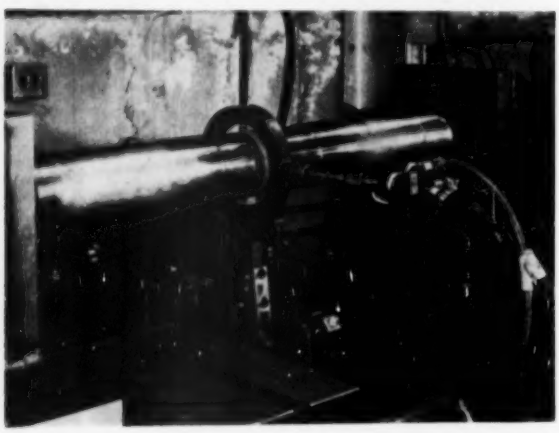
that this will be one of the important processes for welding titanium, and perhaps for the joining of titanium to other metals.

Flash welds in commercially pure titanium have excellent ductility, as shown in Fig. 14. The higher strength titanium alloys produce less ductile welds, but it should be possible to restore ductility by heat treatment, when suitable heat-treating procedures for the various alloys have been developed.

Oxy-acetylene Pressure Welding

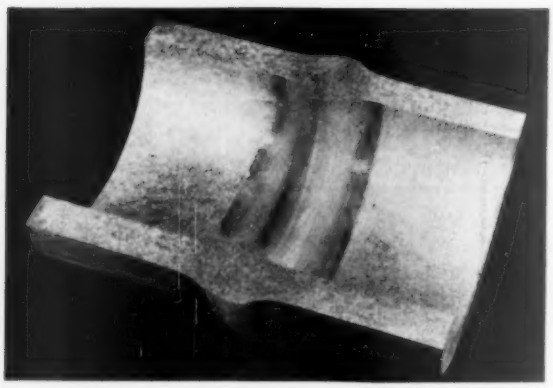
While oxy-acetylene fusion welding of titanium is not feasible, it is possible that oxy-acetylene pressure welding and its companion, induction-heat pressure welding, will be used. Figure 15 shows the oxy-acetylene pressure welding of a 3-in-diam titanium-alloy tube at the Menasco Manufacturing Co. The weld was made in about one minute, with a maximum welding temperature of about 2200° F.

A section of one of these welds is shown in Fig. 16. While the exterior and interior surfaces were oxidized, the oxygen and nitrogen penetration was undoubtedly not very deep. Furthermore, in most such designs the upset metal is usually removed. As in the other welding processes, the ductility of pressure-welded



Courtesy Menasco Mfg. Co.

Fig. 15 Oxy-acetylene pressure welding of titanium-alloy tube



Courtesy Menasco Mfg. Co.

Fig. 16 Section across pressure weld in 3-in. diameter titanium-alloy tube

joints in titanium alloys is dependent on the alloy composition used.

Brazing

Brazing is already being used in the production of assemblies of commercially pure titanium, and may also be useful for the joining of titanium to carbon and alloy steels, stainless steels and other metals.

Research at the Aerophysics Division of North American Aviation, Inc., Armour Research Foundation, Cornell Aeronautical Laboratory, Inc., and Battelle has shown that titanium assemblies can be furnace brazed, induction brazed, resistance brazed and brazed under flux with a carbon arc or gas torch. The method which now appears most likely to produce strong joints is rapid induction heating in a helium or argon gas shield without a flux.

In the Battelle work, strong and reasonably ductile brazes have been made in titanium with pure silver, or with 85–15 silver-manganese alloy. For these alloys, a brazing temperature of 1800–1850° F is required. Figure 17, for example, shows an experimental socket joint between 3/8- and 1/2-in. rounds of commercially

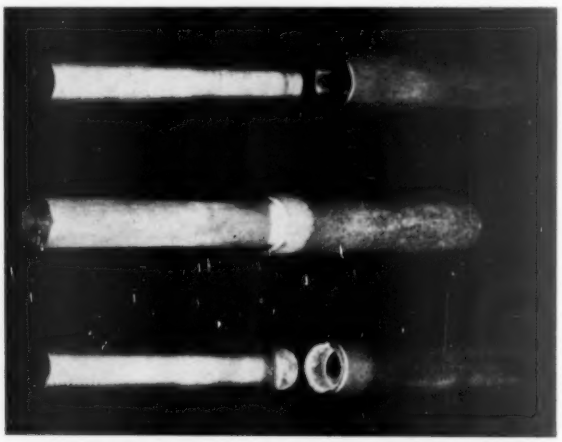


Fig. 17 Experimental brazed socket joint between 3/8- and 1/2-in. round bars of commercially pure titanium

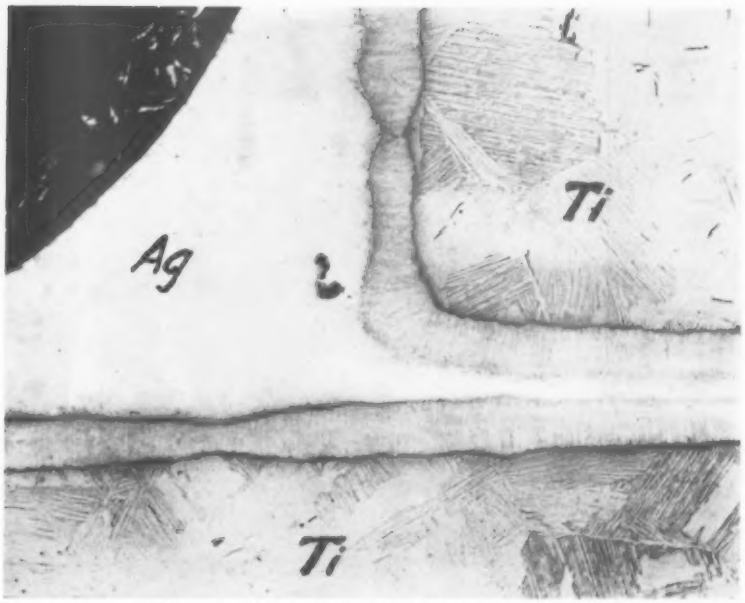


Fig. 18 Cross section at fillet of socket joint in titanium bar, induction brazed with pure silver. 75 ×

pure titanium, induction brazed in an argon shield with pure silver. These specimens broke in tension at a load of 8000 lb, which is equivalent to 40,000 psi shear strength at the braze. For this design and material, the joint efficiency in tension is over 90%. Shear strengths in the range of 30,000 to 40,000 psi have also been obtained in double-lap joints in $\frac{1}{8}$-in. titanium sheet, which were brazed under flux with an oxy-acetylene torch.

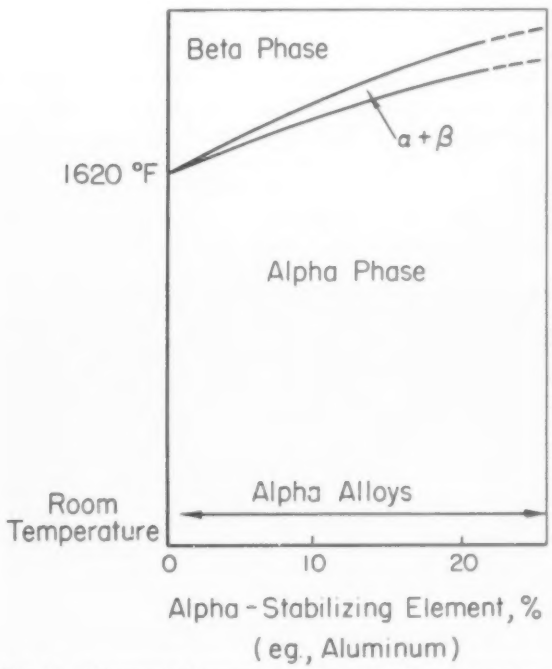


Fig. 19 Schematic diagram showing transformation characteristics of titanium-rich alpha-stabilized alloys

Figure 18 is a photomicrograph of a section of the titanium socket joint induction brazed with pure silver.

Strong brazes have also been made with the lower melting-point silver-base alloys, but the principal problem is to obtain a joint with a useful degree of ductility. The joint brittleness in these brazes is probably caused by the presence of excessive amounts of intermetallic compounds and other brittle phases. One of the present research efforts is to repress the formation of these compounds by brazing at high speeds, and by trying films of other metals to act as diffusion barriers between the titanium and the brazing alloy. Research is also in progress with titanium-base brazing alloys; these produce very strong joints (e.g., 70,000 psi shear strength in socket joints), but the brazing temperature required for these alloys, around 2400° F, is obviously rather high.

ALLOY EFFECTS IN TITANIUM

We now come to the subject of alloy effects in titanium, and the influence of various alloying elements on the properties of welded joints. These alloy effects are quite complex, and our knowledge of them is still developing. Nevertheless, we already have some ground rules. At the risk of oversimplifying, I shall try to give them to you as a guide for the selection of alloys and welding procedures.

Fig. 20 Heat-affected zone adjacent to weld in commercially pure titanium (unaffected fine-grained parent metal at left). 50×

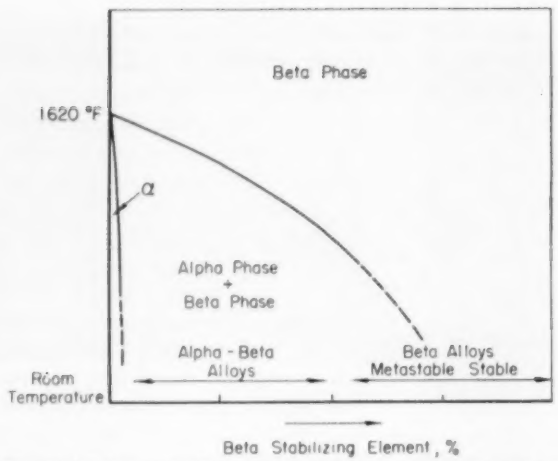


Fig. 21 Schematic diagram showing transformation characteristics of titanium-rich beta-stabilized alloys

Pure titanium exists in two crystal forms. At temperatures above 1620° F, its atomic lattice structure is body-centered cubic. This form of titanium is called "beta." Below 1620° F, the structure transforms to close-packed hexagonal. This form of titanium is called "alpha."

When an alloying element is added to titanium, it has three important effects. First, it strengthens the metal by the solid-solution effect. Second, it can cause profound changes in the alpha-to-beta transformation characteristics of titanium. Third, it may form a compound with titanium. These effects are discussed in the subsequent sections.

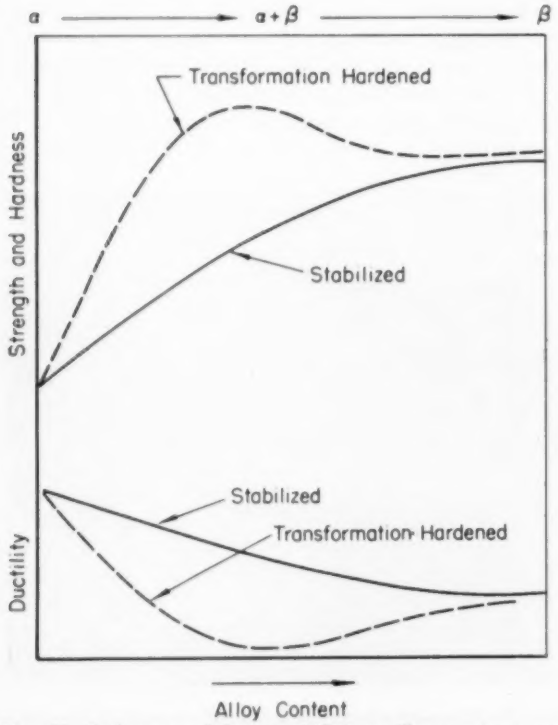


Fig. 22 Influence of beta-stabilizing alloy content on strength and ductility of titanium alloys

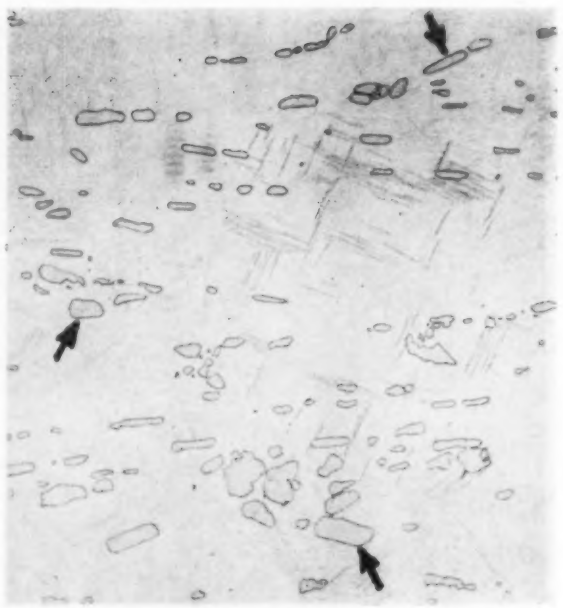


Fig. 23 Titanium carbide in a wrought titanium alpha-beta alloy containing about 0.50% carbon. 250 ×

Solid-Solution Strengthening

All of the alloying elements so far examined have some degree of solid solubility in titanium. As the amount of alloying element in solid solution increases, the strength and hardness of the alloy increase and, correspondingly, the ductility decreases.

The interstitial alloying elements—oxygen, nitrogen and carbon—are very potent solid-solution strengtheners, but they are also strong embrittling agents, so that they can be tolerated up to only a few tenths of 1%. In greater amounts, they make the alloy brittle and also reduce its notch toughness.

The substitutional alloying elements, such as aluminum, iron, manganese, chromium, molybdenum and vanadium, also strengthen titanium by solid-solution hardening. However, the tolerable amounts of these elements, for useful strength and ductility, are relatively large, up to a maximum total content of 10 to 20%.

Fig. 24 Typical arc welds in 1/8-in. sheets of alpha, alpha-beta and beta titanium alloys

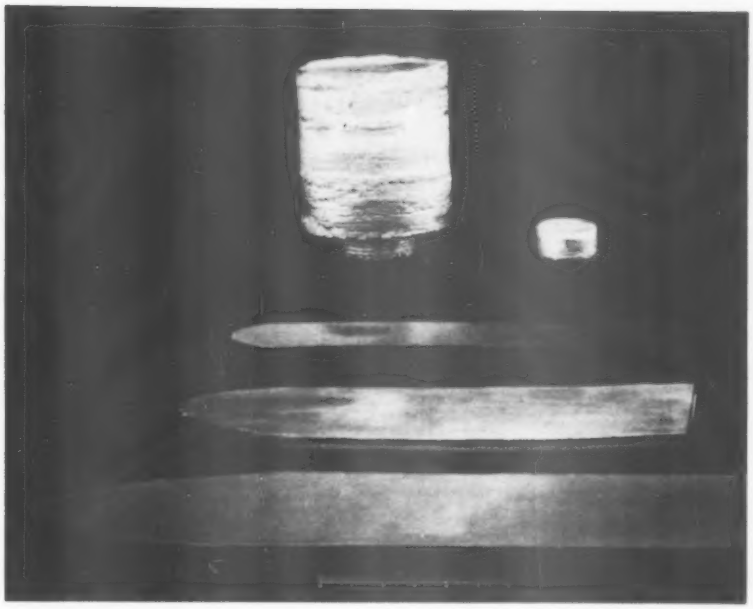


Fig. 25 Typical laboratory-melted titanium ingots and rolled plate and sheet

properties are governed only by the solid-solution effect of the alpha-stabilizing element. In other words, even under rapid cooling, such an alloy transforms completely to alpha, and avoids the so-called transformation hardening and embrittlement that are observed in some of the alpha-beta alloys.

In the parent metal adjacent to welds, the heat effect of welding may produce a grain growth or coarsening; as shown in Fig. 20. So far as is now known, this grain growth does not make the parent metal brittle. The embrittlement that has been observed is generally the result of oxygen and nitrogen pickup, or is caused by other metallurgical effects.

The transformation characteristics of titanium are also changed by a group of elements which "stabilize" the beta phase. This means that these elements, including iron, manganese, molybdenum, chromium and vanadium, lower the transformation temperature, and cause the retention of some or all of the beta phase down to room temperature (Fig. 21).

At very low alloy contents, or up to the limit of solid solubility, the alloy is still in the alpha phase, but as the alloy content increases, the proportion of retained beta phase increases, until at high alloy contents, the alloy is preponderantly or completely in the beta condition.

For the intermediate-range alloy contents, we there-

Transformation Effects

The second important influence of the alloying elements of titanium is to change its transformation characteristics. Some elements, including carbon, oxygen, nitrogen and aluminum, raise the transformation temperature, and thus extend the range of the alpha-phase field (Fig. 19). This behavior is termed "alpha stabilizing." When an alpha-stabilized alloy is cooled from above the transformation temperature, it changes completely to the alpha phase, as does pure titanium.

The rate of cooling has no significant influence on the strength or ductility of the alpha alloys. These

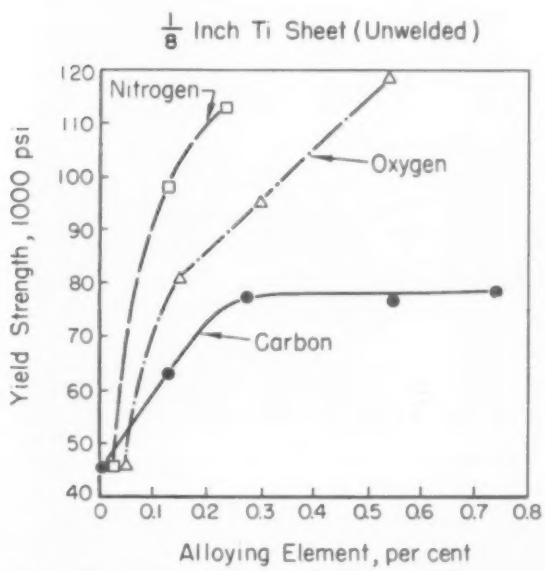


Fig. 26 Influence of nitrogen, oxygen and carbon content on yield strength of 1/8-in. titanium sheet

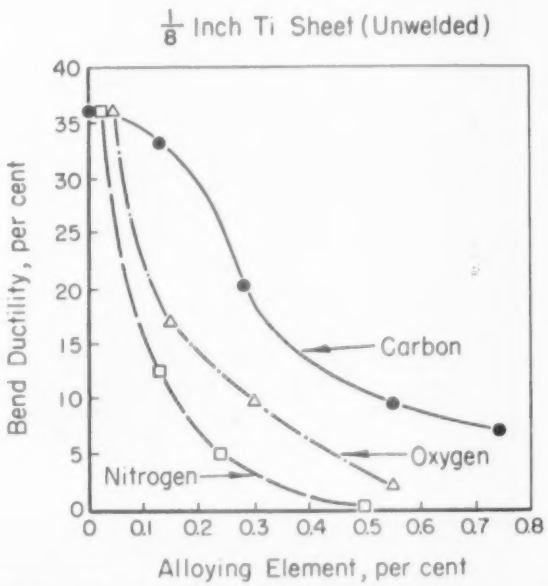


Fig. 27 Influence of nitrogen, oxygen and carbon content on bend ductility of 1/8-in. titanium sheet

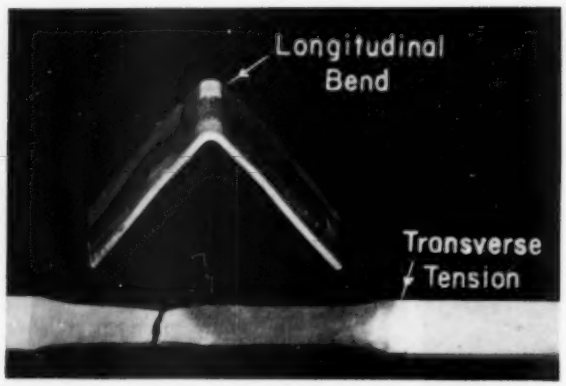


Fig. 28 Typical welded test specimens in 1/8-in. titanium sheet

fore have a two-phase structure, and these alloys are called the alpha-beta alloys. In the fully annealed condition—that is, heat treated to produce the maximum possible transformation of beta phase to alpha phase—the strength of these alloys increases rather uniformly with alloy content, and the ductility decreases (Fig. 22, solid curves). This is called the "stabilized" or "equilibrated" condition, and is the condition in which most titanium alloys of this type are furnished.

On the other hand, if an alpha-beta alloy is rapidly cooled from above the transformation temperature, the phase change from beta to alpha is delayed and modified. This causes a strengthening in the intermediate-composition range, and may also cause a sharp decrease in ductility (Fig. 22, dotted curves).

This transformation hardening, which is directly associated with most forms of weld embrittlement in the alpha-beta alloys, has several causes, and it is not easy to separate them in any particular case.

First, rapid cooling causes more beta phase to be retained, and since beta is the stronger phase, this produces greater strength in the alloy.

Second, a martensitic transformation, from the beta phase to a modified alpha phase, can take place, also with accompanying greater strength and hardness.

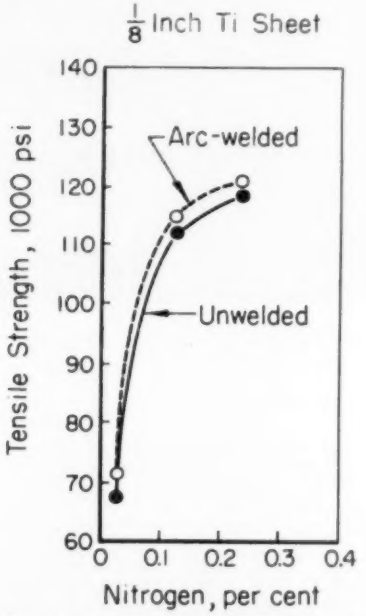


Fig. 29 Comparative tensile strength of unwelded and welded specimens of titanium-nitrogen alloys

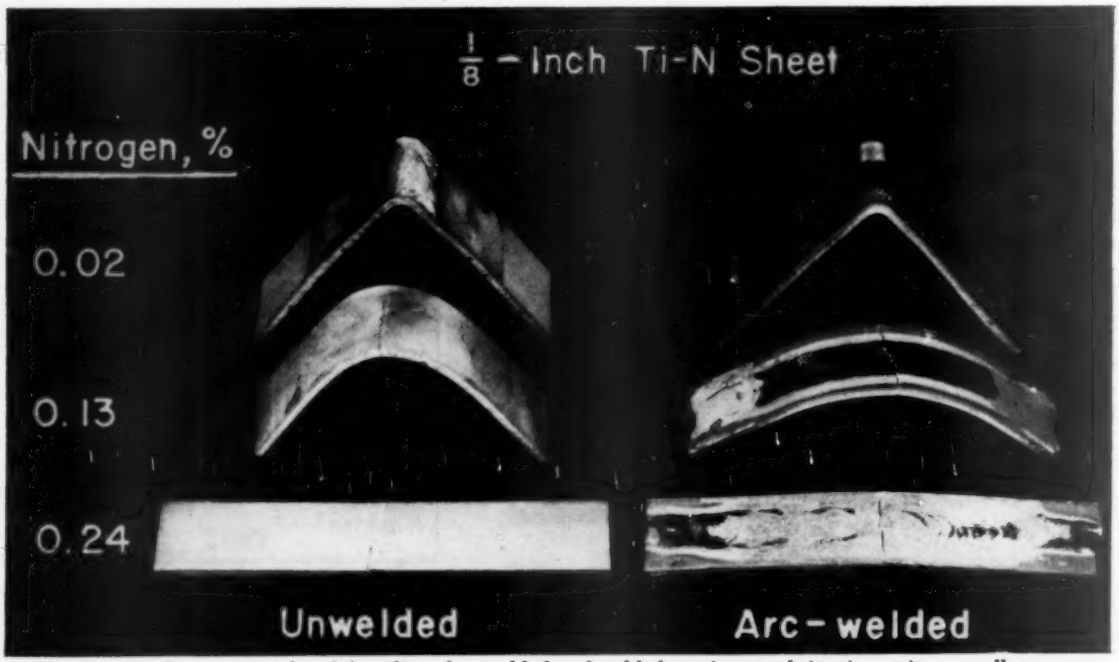


Fig. 30 Comparative bend ductility of unwelded and welded specimens of titanium-nitrogen alloys

Fig. 31 Microcracks in weld metal in titanium – 0.13% nitrogen alloy. 100 ×

Third, at critical cooling rates the beta phase may be strengthened, and sometimes embrittled, either by incipient alpha-phase precipitation along the beta-grain boundaries, or by a similar precipitation, known as coherency hardening, within the beta grains. Resolvable precipitation in finely divided form can also cause embrittlement in these locations.

At the higher contents of the beta-stabilizing elements, the titanium alloys become more sluggish in transformation, and are less and less sensitive to heat treatment. The so-called metastable beta alloys still show some response to heat treatment, and may be embrittled if the heating and cooling conditions are too slow, or if the alloy is held at temperature in the precipitation region.

The stable beta alloys show no such response to heat treatment. However, it requires very high alloy contents—for example, 35% molybdenum—to produce a stable beta alloy.

Compound Formation

Up to now, we have considered the solid-solution and transformation effects. A third factor, which is perhaps less significant than the others, but which also must be mentioned, is the tendency of the alloying elements to form compounds with titanium. Figure 23, for example, shows titanium carbide in a high-strength titanium alloy.

So far as we now know, the compounds are not useful in titanium alloys, since their only apparent effects are to reduce ductility and toughness. Fortunately, compound formation is a very sluggish process, except in the case of titanium carbide and titanium hydride. Other compounds should not be encountered except under abnormal conditions in the highly alloyed metals.

Alloy Classes

In summary, then, from the viewpoint of metallurgical characteristics, we have three kinds of titanium alloys:

First, there is the alpha type, which includes high-purity titanium, commercially pure titanium, and titanium alloyed with only the alpha-stabilizing elements. These single-phase alpha alloys have good strength and ductility. They do not harden when cooled through the transformation range, and consequently the heat effects of welding do not make the weld joint brittle (Fig. 24, left).

Second, are the two-phase, alpha-beta alloys. These are strong alloys, which can be made stronger by heat treatment. They are, however, susceptible to embrittlement as a result of transformation effects, and the heating and cooling cycle of welding often produces such embrittlement (Fig. 24, center).

Third, are the single-phase beta alloys, some of which have an exceptionally good combination of strength and ductility. Some of the beta alloys are stable enough to withstand the heat effect of welding without embrittlement (Fig. 24, right).

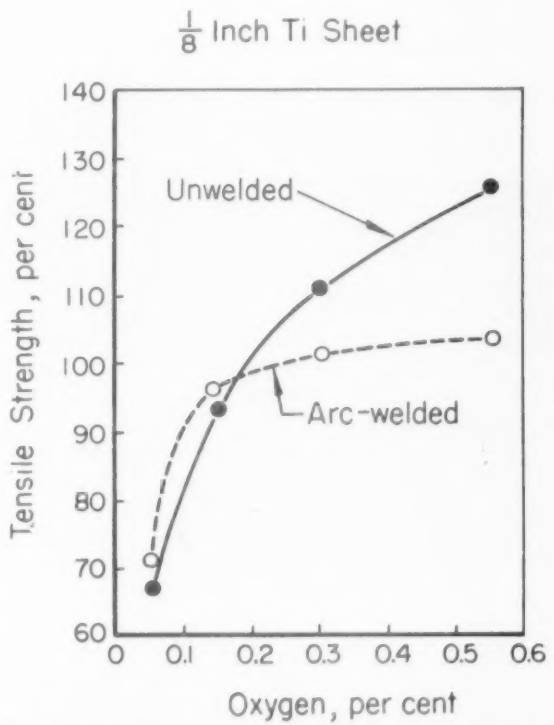


Fig. 32 Comparative tensile strength of unwelded and welded specimens of titanium-oxygen alloys

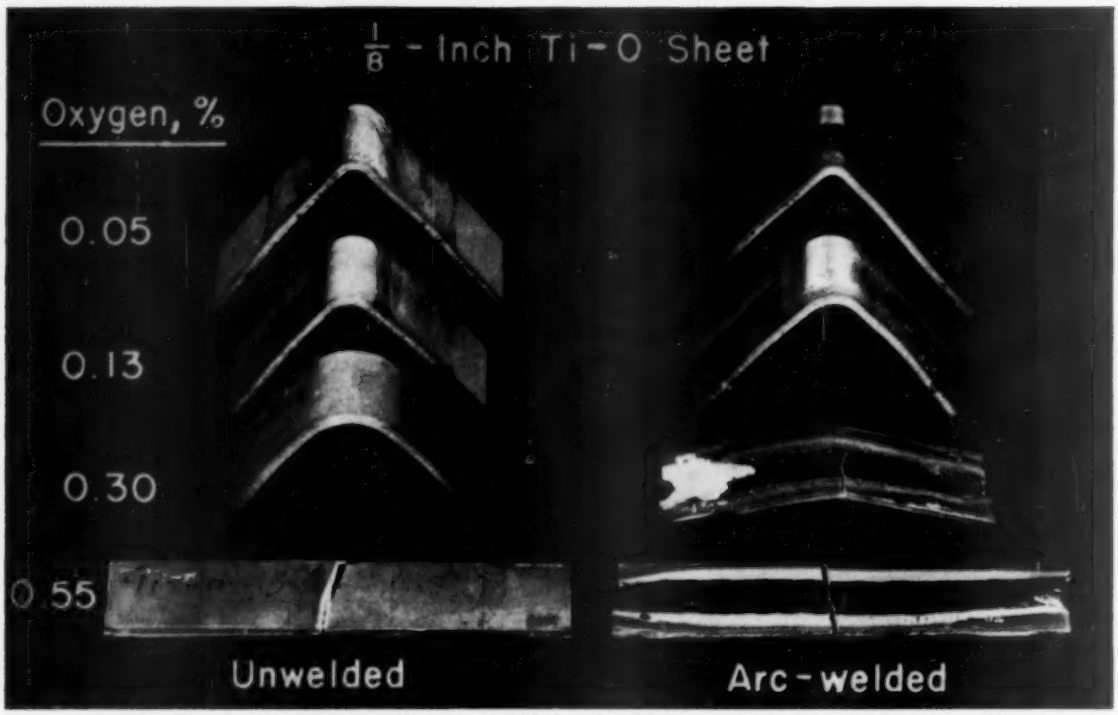


Fig. 33 Comparative bend ductility of unwelded and welded specimens of titanium-oxygen alloys

To illustrate the welding behavior of various titanium alloys, let us now look at the results of some research with experimental alloys.* All of these data are from arc-welding tests, but the response of the alloys to the heat effects of welding is much the same for other processes, such as spot welding and flash welding.

TESTS OF TITANIUM ALLOYED WITH NITROGEN, OXYGEN OR CARBON

In one of these investigations, tests were made to determine the influence of nitrogen, oxygen and carbon on the strength and ductility of arc-welded sheet.† The control alloy was laboratory-melted titanium of commercial purity, with a residual content of about 0.01% nitrogen, 0.05% oxygen and 0.03% carbon. Three other groups of alloys were made, with increasing amounts of either nitrogen, oxygen or carbon, extending to compositions which produce brittleness even in unwelded material.

Figure 25 shows typical laboratory-melted ingots, and rolled plates and sheets for the various welding tests. The 1/8-in. sheets for the nitrogen, oxygen and carbon studies were annealed at 1250° F, air cooled and then pickled to remove surface scale. The tensile strength and bend ductility of the unwelded sheet were then determined.

* Project for Air Materiel Command, Wright-Patterson Air Force Base, at Battelle Memorial Institute under Contract AF 33(038)-21385, "Effect of Carbon, Oxygen and Nitrogen on the Properties of Welds in Titanium Sheet"; Project for Watertown Arsenal at Battelle Memorial Institute under Contract DA-33-019-ord-231, Subproject TB4-15, "Welding of Beta-Stabilized Titanium Alloys."

† These tests are reported in detail in the paper by D. C. Martin, "The Effects of Carbon, Oxygen and Nitrogen on Welds in Titanium," THE WELDING JOURNAL, 32 (3), Research Suppl., 139-s to 154 s (1953).

Properties of Unwelded Sheet

Figure 26 shows the increase in yield strength of the unwelded sheet with increasing alloy content. It illustrates the pronounced solid-solution strengthening effect that is produced by small quantities of either nitrogen, oxygen or carbon.

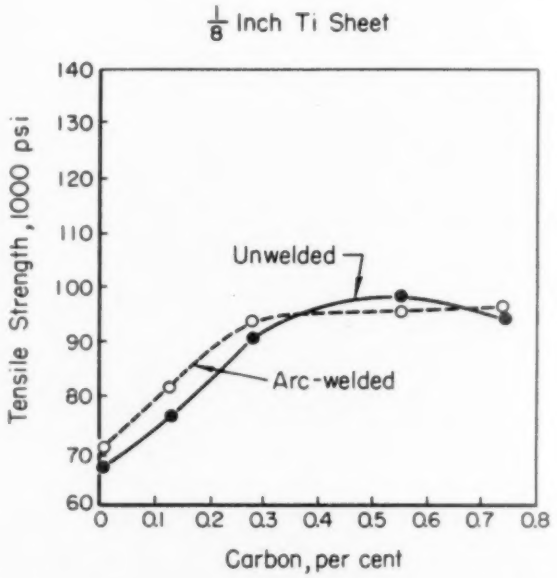


Fig. 34 Comparative tensile strength of unwelded and welded specimens of titanium-carbon alloys

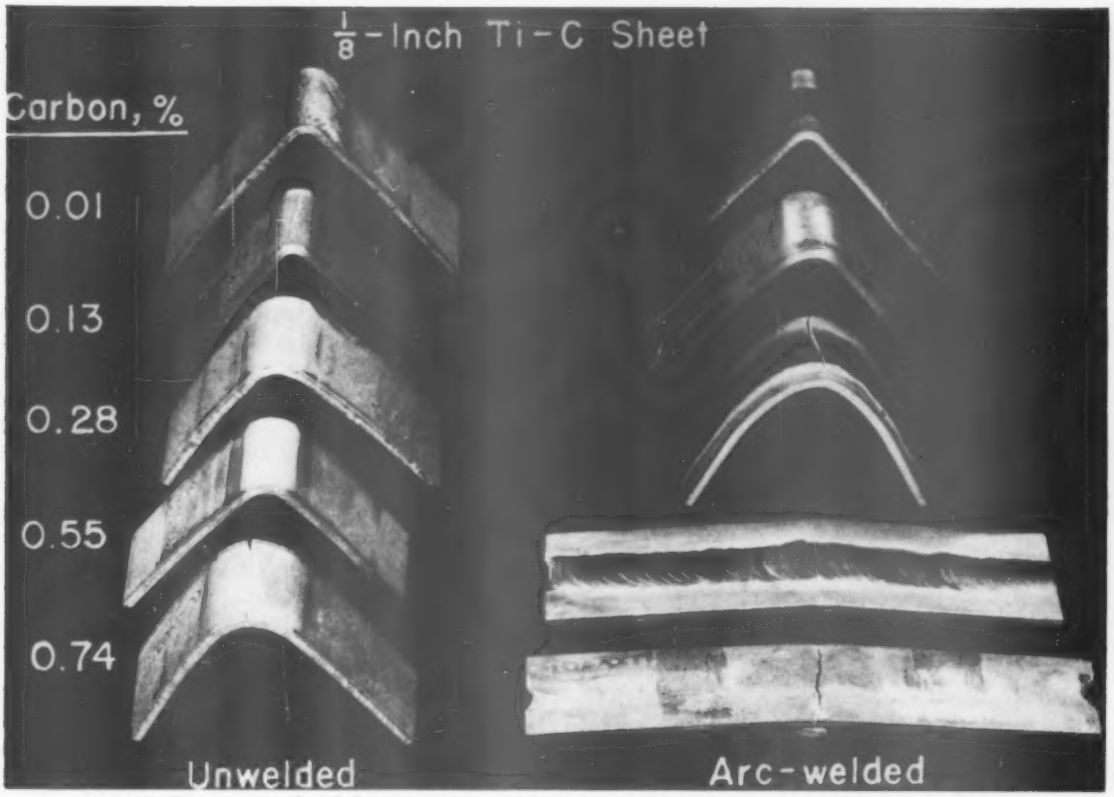


Fig. 35 Comparative bend ductility of unwelded and welded specimens of titanium-carbon alloys

Note that the strengthening effect of carbon stops at about 0.25%. This is approximately the concentration at which titanium carbide begins to form, and no further solid-solution strengthening is obtained.

The strengthening of the unwelded sheet was accompanied by a correspondingly sharp decrease in ductility as the alloy content increased. Figure 27 shows that nitrogen is most detrimental to ductility, while carbon can be tolerated in larger amounts before ductility is impaired.

Properties of Arc-Welded Specimens

Samples of the various alloys were argon-arc welded, using direct current with the electrode negative, in the closed welding chamber, with filler rod of the same composition as the base plate. The welds were made in one pass into a square closed butt joint with a copper bar backing. The as-welded joints were then tested in transverse tension and in longitudinal bending (Fig. 28).

Nitrogen Alloys. Figure 29 shows the tensile strength of welded and unwelded specimens of the nitrogen-containing alloys. The welded specimens were as strong in tension as the unwelded sheet, but the welds were brittle. This brittleness is more evident in the photograph of the bend specimens, Fig. 30. This shows that the ductility decreased as nitrogen content went up, and that the welded specimens were more brittle than unwelded specimens of the same nitrogen content.

The welded specimens were more brittle because the weld metal contained numerous cracks. Figure 31 is a photomicrograph of such cracks in the 0.13% nitrogen alloy. In the higher nitrogen alloys, the cracking was even more severe.

These tests indicate that for useful ductility in welded

Fig. 36 Titanium-carbide network in titanium weld metal containing about 0.55% carbon. 250 ×

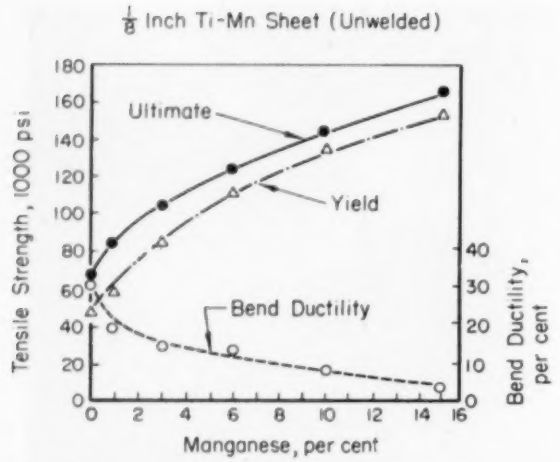


Fig. 37 Influence of manganese content on the strength and bend ductility of unwelded 1/8-in. sheets of titanium-manganese alloys

joints, the nitrogen content should be less than 0.10%, and preferably below 0.05%.

Oxygen Alloys. The tensile strength of welded and unwelded specimens of the oxygen alloys is shown in Fig. 32. At the two higher oxygen contents, the welded specimens were not so strong as the unwelded ones, and the weld-metal fractures were brittle because of weld-metal cracks.

As shown in the photograph, Fig. 33, the bend ductility of these alloys decreased as the oxygen increased. However, the specimens with 0.13% oxygen still had good ductility—about 18% elongation on the tension fibers. At 0.30% oxygen, the welded specimens became quite brittle, because of cracking in the weld metal and heat-affected zone.

These tests suggest that for good ductility in welded joints, the oxygen content should not exceed 0.15%, and a more practical upper limit would be 0.10% oxygen.

Carbon Alloys. Figure 34 shows that the tensile strength of the welded titanium-carbon specimens was the same as that of the base plate for all carbon contents. However, at the higher carbon contents the fractures were always in the weld metal, and were brittle.

Figure 35 illustrates the behavior of this series of specimens in bending. The bend ductility of the unwelded specimens was good up to about 0.55% carbon. The welded specimens showed definite brittleness, in the weld metal, at 0.28% carbon.

The principal cause of the brittleness in the higher carbon welds was not cracking, but titanium carbide, which, as stated before, begins to be present at carbon contents of about 0.25%. In weld metal, this carbide forms dendritic networks which reduce ductility and notch toughness (Fig. 36).

The tests of the carbon alloys indicate that for good weld-joint properties, the carbon content should not be greater than 0.15 to 0.20%.

INFLUENCE OF HYDROGEN

A few words about hydrogen. Thus far there has been no extensive research published on the effects of hydrogen in titanium welding. However, most titanium alloys contain some hydrogen—perhaps 0.004 to 0.010%—and metallurgical studies are in progress on the effects of hydrogen on titanium microstructures.*

From these studies we learn that hydrogen in titanium begins to show an influence in amounts as low as 0.005%. In amounts larger than this, hydrogen is decidedly harmful to notch toughness, but has no effect on tensile ductility and strength until very high contents are reached.

We suspect, also, that hydrogen has been responsible for the occasional porosity found in titanium arc welds. Our cue, therefore, is to avoid contamination of titanium welds by hydrogen from any source—for example, water vapor or hydrocarbon impurities in the inert gas used in arc welding.

Some people even suggest that titanium should not be arc welded in extremely humid weather—but there is no experimental evidence on this, one way or the other.

* Project for Watertown Arsenal at Battelle Memorial Institute under Contract DA-33-019-ord-938, "The Effect of Hydrogen on the Mechanical Properties of Titanium." See also C. M. Craighead, G. A. Lenning and R. I. Jaffee, "The Nature of the Line Markings in Titanium and Alpha-Titanium Alloys," *Jl. Metals* v. 4 p. 317-319 (December 1952).

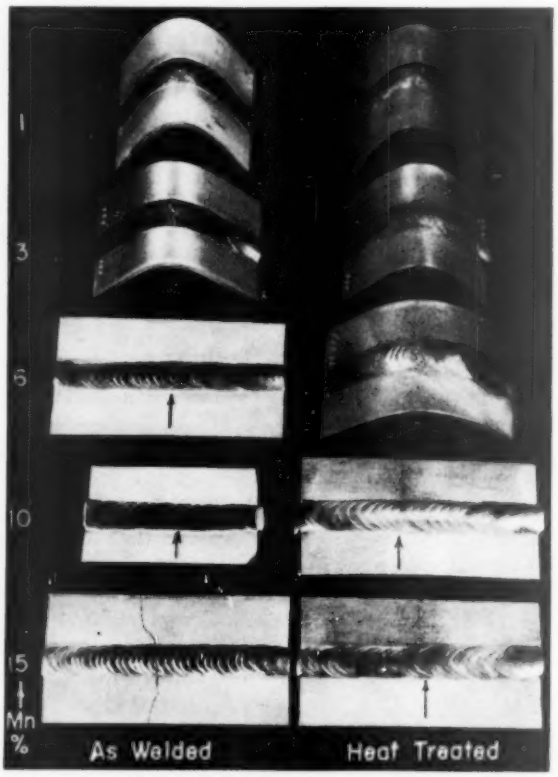


Fig. 38 Bend ductility of arc-welded specimens of titanium-manganese alloys

TESTS OF TITANIUM ALLOYED WITH BETA-STABILIZING ELEMENTS

We now come to the welding behavior of titanium alloyed with beta-stabilizing elements, among which are iron, manganese, molybdenum, chromium and vanadium. These elements, when used in moderate amounts, produce the two-phase alpha-beta alloys which are sensitive to heat treatment, and which can be embrittled by welding. The same elements in higher amounts produce the beta alloys, which are less sensitive to heat treatment.

As examples of the fundamental welding behavior of the alpha-beta and beta alloys, I will describe two series of tests—one on titanium-manganese alloys, and the other on titanium-chromium alloys.* These experimental alloys contained manganese or chromium in amounts ranging from 1 to 15%. All of the alloys, in addition, had the normal residual content of oxygen, nitrogen and other impurities.

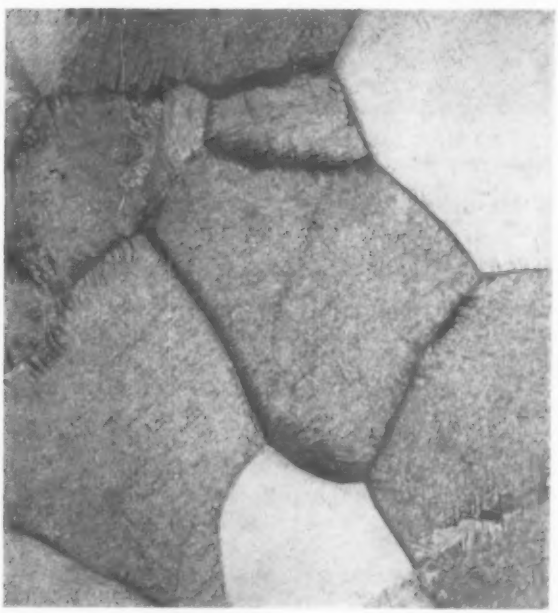


Fig. 39 Coarse-grained structure in heat-affected parent metal of an arc weld in titanium – 6% manganese-alloy sheet 100 ×

The laboratory-made ingots were rolled to 1/8-in. sheets, which were then given an equilibrating heat treatment, by heating to 1350° F for 1 hr., slow cooling at 1150° F, and quenching in water. The water quench was not essential to this heat treatment. Air cooling from 1150° F would have produced the same result in these relatively thin sheets.

The control specimens, which contained no manganese or chromium, but only the residual elements, were annealed at 1500° F and air cooled.

Samples of the 1/8-in. sheets were heliarc welded with straight polarity in the controlled-atmosphere chamber, using strips of the base metal for filler rod. The welds were made in a single pass into a 90-deg vee-groove with a steel backing bar.

* The tests are described in detail in the paper by G. E. Faulkner, G. B. Grable and C. B. Voldrich, "The Effects of Iron, Manganese, Chromium and Molybdenum on Welds in Titanium," to be published in this JOURNAL.

Fig. 40 Dendritic structure of weld metal in a titanium alloy 100 ×

Titanium-Manganese Alloys

Properties of Unwelded Sheet. Figure 37 shows the tensile and yield strengths and the bend ductility of the unwelded, stabilized specimens of the unalloyed titanium and the manganese-alloy sheets. The unalloyed titanium had a yield strength of 50,000 psi and an ultimate strength of 67,000 psi. The strength of the alloys increased steadily with the manganese content, to a maximum at 15% manganese, of about 150,000 psi yield and 170,000 psi tensile strength. The bend ductility, on the other hand, decreased steadily from 33% for the unalloyed titanium to 2% or less for the highest manganese content.

The alloys with intermediate manganese contents had the two-phase alpha-beta structure, with the beta content increasing as the manganese increased. The 15% manganese alloy was a metastable beta, which contained some alpha phase as a result of the equilibrating heat treatment that was used. Even if it had been quenched from above the transformation temperature, to produce an all-beta structure, the 15% manganese alloy would have had low ductility. This is characteristic of the high-manganese alloys, because of the excessive solid-solution hardening effect of manganese in the beta phase.

Properties of Arc-Welded Specimens. Figure 38 shows the results of bend tests on arc-welded specimens of the titanium-manganese alloys, in the as-welded condition, and heat treated after welding.

The ductility of the as-welded specimens decreased steadily with increasing manganese content and, at

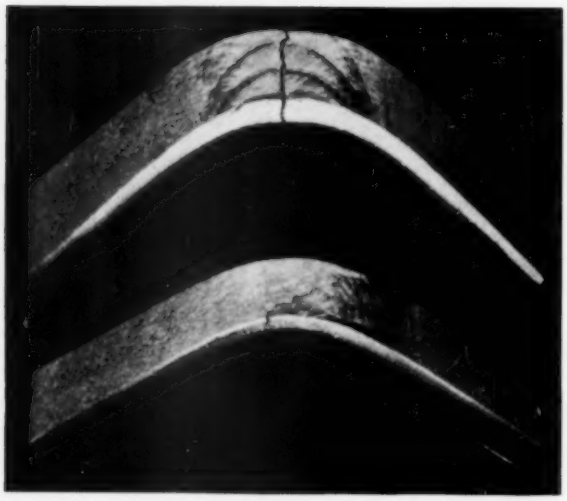


Fig. 41 Transverse bend tests of arc-welded specimens of titanium – 6% manganese-alloy sheet, after beta anneal (upper specimen bent on center of weld, lower specimen bent on fusion line)

6% manganese, the specimen was almost completely brittle. This brittleness is the result of transformation hardening which takes place during cooling after welding. In the heat-affected zone of the parent metal, this embrittlement may be caused by grain-boundary alpha precipitation, as illustrated by the whiskery appearance of the grain boundaries in the photomicrograph, Figure 39. However, submicroscopic alpha precipitation within the grains—the so-called coherency hardening—may also cause brittleness.

In the weld metal, particularly at higher alloy contents, the brittleness may be aggravated by dendritic segregation which occurs when the weld metal solidifies (Fig. 40). This segregation produces areas with compositions that may be inherently brittle, and heat treatment is not very effective in restoring ductility to such segregated metal.

The manganese-alloy weld specimens shown in the right-hand column of Fig. 38 were heat treated in an attempt to eliminate the brittleness caused by transformation hardening during welding. The heat treatment was similar to that which the base metal had received before welding—that is, 1350° F for 1 hr., a slow cool to 1150° F and then a water quench. However, this treatment restored no ductility, except a small amount in the 6% manganese alloy.

Pieces of the 6% manganese-alloy weld were then beta-annealed, by heating at 1500° F for 2 hr and cooling slowly for 24 hr to room temperature. As shown in Fig. 41, this treatment produced a good recovery in ductility, up to about 15% elongation, but no doubt the tensile strength was lowered.

Welds with Commercially Pure Titanium Filler Metal. A second method of making ductile weldments in the high-strength alpha-beta alloys, which may be of considerable practical significance, is to use unalloyed titanium as the filler metal.

Figure 42 shows a cross section of an Aircomatic

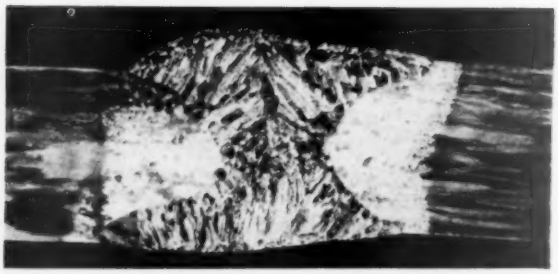


Fig. 42 Cross section of arc-welded joint in 1/2-in. plates of titanium – 6% manganese-alloy, using commercially pure titanium filler metal

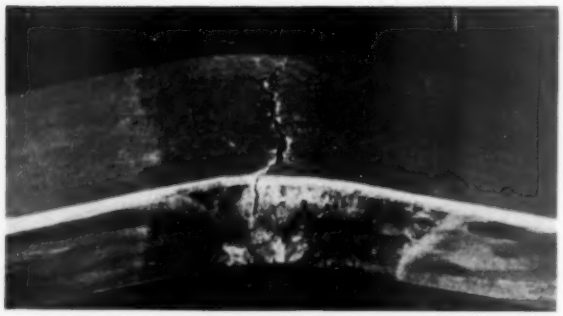


Fig. 43 Transverse bend in arc-welded joint in 1/2-in. titanium-manganese-alloy plate, made with commercially pure titanium filler wire

arc weld made with commercially pure titanium filler wire in 1/2-in. plates of 6% manganese alloy. The weld was shielded with argon, using direct current with the electrode positive, and was made in one pass on each side of the 45-deg double-vee joint. The resulting weld metal contained about 3% manganese, brought in from the melted parent metal.

In the as-welded condition, this joint had a good bend ductility—about 15% elongation in the weld metal before fracture—but all of the bending was in the softer weld metal, with no yielding in the hardened parent metal (Fig. 43). The transverse tensile strength of the joint was 120,000 psi. Since the base metal had a tensile strength of about 130,000 psi, the joint efficiency was over 90%.

The important characteristic of joints of this type is that they offer a good compromise between strength and ductility, and this procedure should find uses in the construction of some weldments.

Titanium-Chromium Alloys

Properties of Unwelded Sheet. Figure 44 shows the strength and ductility of the unwelded, stabilized, titanium-chromium alloys. Starting with the unalloyed titanium, the yield and tensile strengths increased with chromium content, up to a maximum of about 140,000 psi yield and 150,000 psi tensile strength.

The bend ductility was somewhat low in the intermediate chromium alloys, which were the two-phase, alpha-beta type. The 15% chromium alloy was a

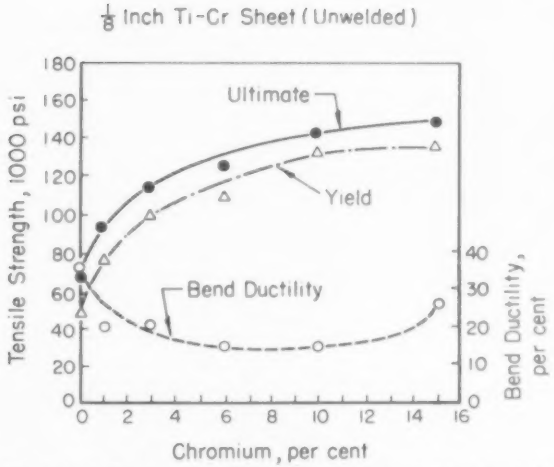


Fig. 44 Influence of chromium content on the strength and bend ductility of unwelded 1/8-in. sheets of titanium-chromium alloys

metastable beta, and had a good bend ductility of 25%.

Properties of Arc-Welded Specimens. Figure 45 shows the results of bend tests on arc-welded specimens of the titanium-chromium alloys, in the as-welded condition, and heat treated after welding.

The left-hand column of specimens shows that the 1 and 15% chromium alloys, which were ductile before welding, both had very ductile weld joints. You will remember that the 15% chromium alloy, at the lower left, had a base-metal tensile strength of 150,000 psi. The weld, made with 15% chromium filler metal, is the most ductile weld in high-strength titanium alloy that has been produced thus far in this investigation. This demonstrates the behavior of a beta alloy which is sufficiently stable to go through the heating and cooling cycles of arc welding without transformation hardening and embrittlement.

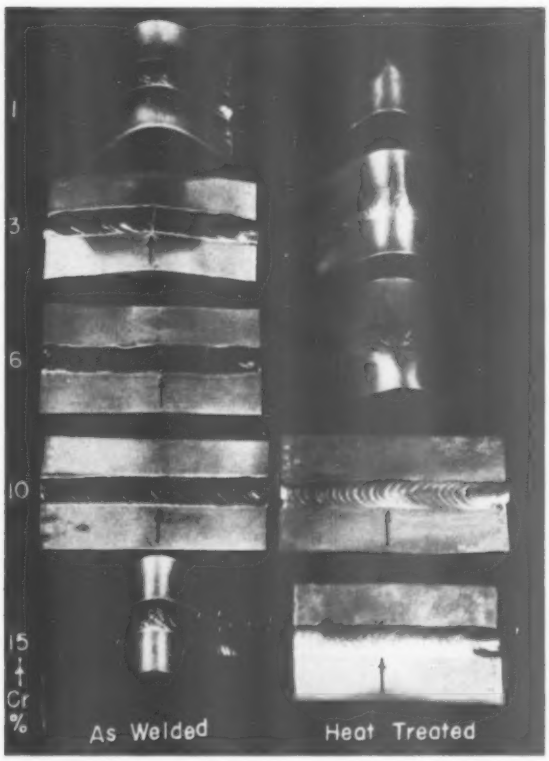


Fig. 45 Bend ductility of arc-welded specimens of titanium-chromium alloys

The right-hand column of Fig. 45 shows weld specimens heat treated after welding. The specimens with 1, 3, 6 and 10% chromium were given the equilibrating heat treatment previously described. This improved the bend ductility of the three low-chromium alloys.

The 15% chromium-alloy weld, at the lower right of Fig. 45, was heat treated by beta quenching; that is, by heating above the transformation temperature, at 1400° F, and then quenching in water. The beta quench produced no hardening in this specimen, but the weld metal was completely embrittled.

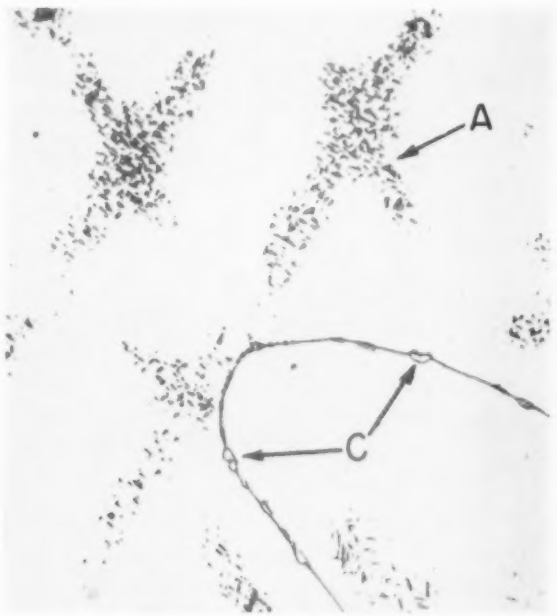


Fig. 46 Photomicrograph of weld metal in titanium – 15% chromium weld metal ("A" indicates alpha-phase precipitate on a dendritic pattern. "C" indicates grain-boundary precipitate, probably a titanium-chromium compound) 500 ×

A photomicrograph of the heat-treated 15% chromium weld metal, Fig. 46, shows an oriented alpha-phase precipitation, *A*, which reflects the segregated condition of the weld metal. It also shows a fine precipitate, *C*, along the grain boundaries, which probably caused the brittleness in the weld metal. It is believed that this precipitate is a titanium-chromium compound which formed during the heat treatment at 1400° F.

Figure 47 shows a photomicrograph of the same 15% chromium weld metal, at the same magnification but with oblique illumination. Note that the particles on the grain boundaries stand out in relief. This indicates that the particles are harder than the surrounding

Fig. 47 Photomicrograph of weld metal in titanium – 15% chromium alloy, showing grain-boundary precipitate (oblique illumination) 500 ×

beta phase, and supports the conclusion that this is a titanium-chromium compound.

The available equilibrium data for the titanium-chromium system suggest that if this weld had been heat treated at a higher temperature, say 1500° F, the embrittling compound might not have formed. The lesson this teaches is not to forget that the high-alloy weld metals may be strongly segregated, with areas varying in alloy concentration, and that this must be taken into account when heat treatments for high-alloy titanium weldments are selected.

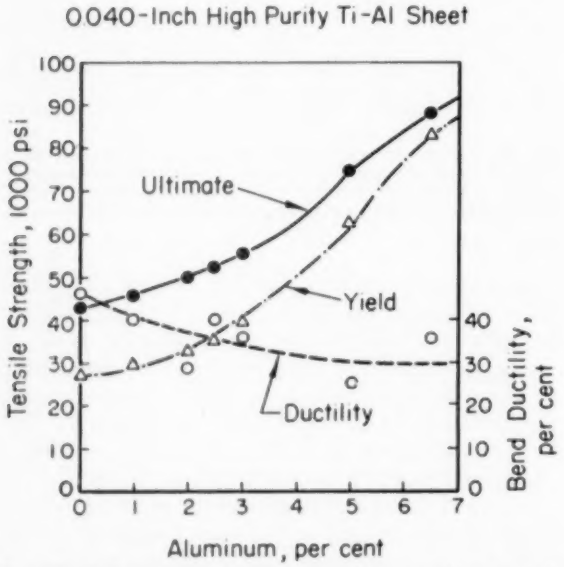


Fig. 48 Influence of aluminum content on the strength and bend ductility of unwelded sheets of titanium-aluminum alloys

TESTS OF AN ALPHA-STABILIZED TITANIUM-ALUMINUM ALLOY

It was stated earlier that titanium alloys of the all-alpha type do not respond to heat treatment, and consequently are not susceptible to transformation hardening and embrittlement from welding. The results of some experiments with titanium-aluminum alpha alloys will illustrate this.*

The graph, Fig. 48, shows the strength and ductility of thin sheets of high-purity titanium alloyed with aluminum up to 6.5%. The solid solution effect of the aluminum increases the strength, particularly at alloy contents of 5% and above. The ductility decreases only gradually, and even for the 6.5% aluminum alloy, remains at the high level of 30%.

The weldability of the high-purity titanium-aluminum alloys was remarkably good, as shown in the longitudinal bend-ductility graph, Fig. 49. In comparison with the unwelded sheet, the arc-welded specimens of the titanium-aluminum alloys retained most of their original bend ductility, with a minimum of about 25% elongation.

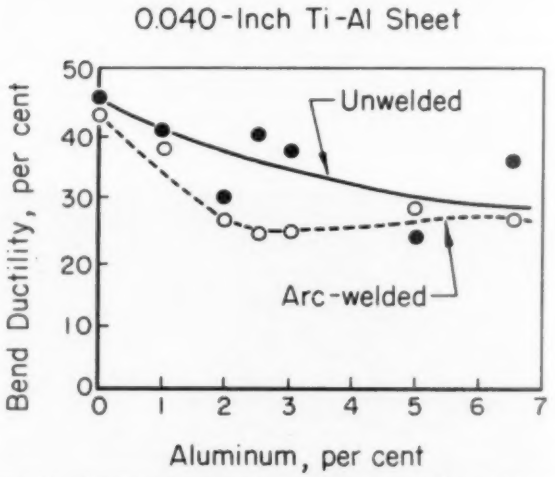


Fig. 49 Comparative bend ductility of unwelded and arc-welded specimens of titanium-aluminum-alloy sheet

It must be remembered that these alloys were made with high-purity titanium which has almost no residual-element content. When commercially pure titanium is used for the making of these alloys, the tensile and yield strengths are 20,000 to 30,000 psi higher, because of the added strengthening effect of residual oxygen and nitrogen. The weldability of these stronger alpha alloys is not greatly diminished. Figure 50, for example, shows a photograph of an arc weld in 1/16-in. sheet of commercially pure titanium alloyed with 3% aluminum. The bend ductility of the as-welded specimen is at least 25%, at a base-metal tensile strength of about 90,000 psi.

* Refer also to H. R. Ogden, D. J. Maykuth, W. L. Finlay and R. I. Jaffee "Mechanical Properties of High-Purity Ti-Al Alloys," *Jnl. Metals*, v. 5 Sec. 2 pp. 267–272 (February 1953).

Fig. 50 Longitudinal bend in arc-welded specimen of $^1/_{16}$-in. sheet of titanium – 3% aluminum alloy

It seems certain that, among the future titanium alloys for welding applications, we will have some all-alpha alloys, stabilized and strengthened with elements such as aluminum and the interstitial alloying elements. An important point to remember is that the aluminum-stabilized alpha alloys are stronger, at temperatures of 700 to 900° F, than many of the alpha-beta and beta alloys.

CONCLUSION

To sum up, at this stage of progress in titanium technology, the welding characteristics of titanium alloys are about as follows:

1. Titanium alloys are not difficult to weld, but we must be careful to protect the molten weld metal and the adjacent hot base metal from air, to prevent the embrittling effect of oxygen and nitrogen pickup.

2. Moreover, we cannot make ductile welds in titanium alloys which contain excessive amounts of oxygen, nitrogen or carbon, nor can we use filler metals which contain too much of these elements.

3. Alloys of the single-phase alpha type, such as high-purity titanium, commercially pure titanium and the titanium-aluminum alloys, make good weld joints with excellent ductility.

4. Alloys of the two-phase alpha-beta type will always present some weld-ductility problems; but as our knowledge of the metallurgical characteristics of these alloys increases, welding procedures and heat treatments should be developed which will improve weld ductility and make these alloys more applicable in welded construction. Furthermore, by using the more ductile filler metals, such as unalloyed titanium, we can make reasonably strong and ductile weldment in some of the alpha-beta alloys.

5. Alloys of the single-phase beta type, such as the high-chromium alloys, also can make strong and ductile weldments. However, ductile welds are not so intrinsic a property of beta alloys as of the single-phase alpha alloys.

There is still a lot to learn about other aspects of titanium welding metallurgy, and about the design and performance of titanium weldments. We need to know more about the influence of oxygen, nitrogen, carbon and hydrogen on the transformation characteristics of the alloys containing the beta-stabilizing elements. We need more information on suitable heat treatments for welded joints, and on the aging characteristics of welds at elevated service temperatures.

There are yet no extensive or reliable data on the strength and ductility of multiple-pass arc welds, which produce complex heat effects in the weld and base metal. We should study the potential advantages of filler metals whose compositions are different than the base metal, for the making of ductile weld joints. More information is needed on notch toughness and strain-rate sensitivity; on the fatigue strength of welded joints; and on the structural performance of titanium weldments at various temperatures through the transition range from ductile to brittle behavior.

Nevertheless, the industry has already made a very substantial advance, and we are now at the threshold of important new developments. These will be not only in alloy composition and welding metallurgy, but in the other technologies—extractive metallurgy, melting, forging, rolling and casting.

With these developments, we can expect vigorous progress in the applications of titanium and its alloys, and in the use of welding in titanium fabrication. In the immediate future, however, we should not expect to be able to use all of the extra-strong titanium alloys in weldments. Instead, we should accept the benefits of the moderately strong alloys, which have such good welding characteristics and weld-joint properties—and designers should give thought to applying these alloys wherever possible for welding applications.

It was only a few years ago that we were learning how to weld the high-strength alloy steels, the armor-plate steels, the strong aluminum alloys—and the problems sometimes appeared insurmountable. Yet, now, the welding of these metals is common practice.

Today, we find it difficult to make good welds in some of the titanium alloys—but if past performance in the welding industry is any criterion, we can surely look forward to the time when many of the high-strength titanium alloys will be everyday materials in our welding work.

Low-Hydrogen Welding Rods

If special precautions are not taken, decrease of the undesirable oxygen content of weld metal will lead to an unwanted increase in the hydrogen content. A new type of electrode, the so-called "low-hydrogen" welding rod, has therefore been developed

by J. D. Fast

INFLUENCE OF THE COATING OF THE ELECTRODE ON THE GAS CONTENT OF THE DEPOSITED METAL

IN MOST countries of the world only coated electrodes are used for electric arc welding, particularly for welding in air. The chief function of the coating is the protection of the molten metal from the oxygen and nitrogen in the air. Its second and nearly as important function is the evolution of sufficient gas for the globules, developed during the welding process at the end of the electrode, to be driven out with great force, giving rapid transfer of the metal to the work piece and good penetration (even in the case of "overhead" welding).

The coating of electrodes always contains metal oxides. Should these metal oxides easily yield large quantities of oxygen to the molten metal, the above-mentioned favorable function of the coating, viz., that of protecting the metal from oxygen (and nitrogen attack) would be illusory. By using very stable oxides only and by adding reducing metal powders to the coating, the latter was improved to the point of yielding a minimum quantity of oxygen to the weld metal. However the greater the success in combating the evil of oxygen absorption, the nearer becomes the incidence of another nuisance, viz., the absorption of considerable quantities of hydrogen.

The combination of compounds contained in the coating of an electrode releases water vapor on heating. This water vapor enters the arc atmosphere and is in contact with the molten metal during the welding process. Hydrogen and oxygen being soluble in this metal to a certain extent, the following equilibrium is ultimately approximated:

$$H_2O \rightleftarrows 2[H] + [O] \qquad (1)$$

The square brackets indicate the hydrogen and oxygen in the metal in the dissolved state. (H and O have been used as symbols instead of H_2 and O_2 because hydrogen and oxygen are present in the metal in the atomic and not in the molecular state.) In equilibrium—depending on the temperature T—a simple relationship holds approximately, between the percentages of hydrogen and oxygen in the metal and the pressure $p(H_2O)$ of the water vapor outside. This relationship is the following:

$$\frac{[\%H]^2 \times [\%O]}{p\ (H_2O)} = C(T) \qquad (2)$$

showing that the smaller the oxygen content of the metal and the larger the pressure of water vapour, the larger is the hydrogen absorption by the metal.*

It is indeed a fact that on improvement of the electrode coatings with regard to the release of oxygen to the metal, the hydrogen absorption by the metal increased automatically at an unchanged water vapor content of the arc atmosphere. This was attended by various disagreeable phenomena.

DETRIMENTAL ACTION OF HYDROGEN

Hydrogen is absorbed by the molten metal during the welding process. The solubility of hydrogen in iron diminishes with decreasing temperature; at the solidification point it even drops abruptly. Thus the absorbed hydrogen will be partly released again during the cooling process. If the metal is still liquid the excess gas can leave it in two ways: (1) gas bubbles may form in the liquid metal and rise to the surface under the influence of the hydrostatic pressure; (2) the atoms may diffuse to the outer surface and recombine to form molecules.

We have already discussed extensively in this review the effect of these two processes on the welding process itself. In some circumstances, e.g., when relatively large quantities of sulfur are present in the metal, the formation of gas bubbles during the cooling process may cause porosity of the weld. The article cited under Reference 1 gives more details on the influence of sulfur.

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* The state of equilibrium to which eq. 2 is applicable is never completely attained during the welding process. Nevertheless the formula will be useful for the following semiquantitative discussion.

As soon as the deposited metal has completely solidified, further release of hydrogen can only be effected via the second process: diffusion of hydrogen atoms through the metal and subsequent recombination at the surface to molecules. The thicker the metal from which the gas is to be released and the lower the temperature,* the longer the diffusion process will take. Hence if the metal to be welded is very thick, a large quantity of hydrogen will be retained, in the first place owing to the long distance the atoms have to travel in the diffusion process and in the second place by the rapid cooling caused by the thickness of the metal. In this second process, as in the first one, the presence of sulfur may retard the release of hydrogen still more.[2]

The excess hydrogen, left in the metal after the cooling process, can collect under very high pressure in molecular form in internal microscopic or submicroscopic voids. The following may serve to explain this.[2] Let us suppose solid iron in equilibrium with hydrogen of 1 atmosphere at 1520° C to cool down so rapidly to room temperature that no hydrogen at all is released. At the temperature of 1520° C about 14 cm^3 hydrogen was dissolved in the atomic form in every hundred grams of iron. At room temperature less than 0.1 cm^3 hydrogen is present in this form per 100 gs of iron in the equilibrium state (with hydrogen at 1 atm outside the iron). However, 14 cm^3 hydrogen are actually still present in the iron after quenching and this corresponds to an external equilibrium pressure of more than 20,000 atmospheres.

The rate of diffusion of hydrogen in iron is still relatively high at room temperature; a considerable quantity of hydrogen will be released after recombination at the outer surface.† This process of recombination to molecules will also take place at the surface of each small cavity or included piece of slag in the interior of the metal. Most important of all: at low temperatures the process does not take place at a perceptible rate in the reverse direction since only atoms can diffuse through the metal and since dissociation of hydrogen molecules at the surface is a very slow process at low temperatures. As long as the metal is supersaturated with hydrogen the diffusion to the cavities will proceed, even if the pressure in the cavities rises to very high values. In the case under discussion this pressure can increase to thousands of atmospheres. Welding with normal types of electrode may therefore be expected to lead to the building up of large pressures of hydrogen in tiny voids within the weld. Consequently test bars made from the metal of such a weld show so-called fisheyes on the surface of fracture (Fig. 1). These fisheyes show minor holes or inclusions in their center. In these regions the metal could not deform plastically because of the high hydrogen pressure and the stresses developing during the elongation. During the deformation of the test bar this results in brittle fractures on a very small scale in these regions. It was found that the pressure in the micro voids only increases to dangerously high values during the elongation. Hence fisheyes can only be formed after much larger deformation than ever occurs in a construction and therefore cannot adversely influence the strength of the welded joint.

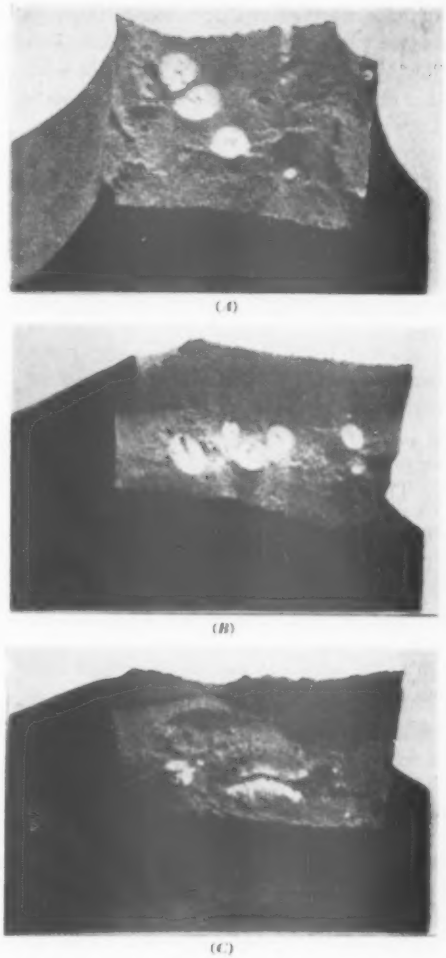

Fig. 1 Fisheyes on the surface of fracture of test bars, made from weld metal, caused by the metal containing (a) gas bubbles, (b) coarse slag inclusions, (c) finely divided inclusions (Bennek, H., and Müller, F. H., Arch. Eisenhüttenwesen 14, 605–615 (1940–41))

What is much more serious, the presence of much hydrogen under very unfavorable conditions may lead to cracking in or near to the weld. This may happen with electric welding when the carbon content of the steel to be welded is very high. These cracks near the weld can be accounted for as follows: In the region of the weld the metal is heated to the austenite range (γ-iron range) during the welding process; the subsequent rapid cooling can give rise to the formation of martensite[3] (carbon-containing body-centered cubic iron with tetragonal deformation). The attendant changes in volume may in their turn cause the develop-

* This holds good for iron in only one modification, e.g., ferrite, for in austenite the rate of diffusion of hydrogen is smaller.

† If a newly made weld is immersed in water, in many cases small gas bubbles will be formed at the surface for a long time.

ment of cracks of microscopic size. High hydrogen pressures may develop in these cracks unless electrodes of the low-hydrogen type are used, and these may grow into macroscopic cracks in the relatively brittle region around the weld.

Hydrogen may also contribute to cracking of the still hot metal of the cooling weld itself (so-called "hot-cracking").[4] Further discussion of this subject in the present paper would lead us too far.

COATING OF SOME TYPES OF ELECTRODES

It is evident from the preceding sections that the water content of the coating has increased in importance with the decrease of the oxygen transmitted by the coating to the metal. We shall go somewhat deeper into the problem by discussing the chief types of electrodes. They are, respectively:

1. The bare electrode.
2. The dead-soft electrode (completely inorganic coating, chiefly consisting of iron oxides, carbonates and silicates).
3. The mineral-coated electrode with ferromanganese and ferrosilicon added to the coating.
4. The organic electrode containing large quantities of TiO_2 (rutile), although its most characteristic constituents are certain organic compounds.
5. The basic or low-hydrogen electrode, to be discussed later in this paper.

The two first-mentioned types of electrodes (the bare electrode and the dead-soft electrode) are hardly used any more nowadays. With the exception of the last type (the low-hydrogen electrode) all coated electrodes contain substances, e.g., waterglass and organic compounds, which evolve relatively large quantities of water vapor during the heating process. Starting from the equilibrium formula (2), we shall try to compute the hydrogen content of the metal deposited by the various types of welding rods. To do this we shall have to know in the first place the value of the constant $C(T)$ from eq. 2 for about 1540° C, i.e., at a temperature just above the melting point of iron (1539° C). We have pointed out in another paper[5] that at this temperature:

$$C = 1.1 \times 10^{-6},$$

if the water vapor pressure is given in atmospheres and the hydrogen and oxygen content of the metal in weight by percent. Moreover, we shall need two experimental values for each type of welding electrode, viz. the water vapor content of the arc atmosphere and the oxygen content of the liquid metal.

With regard to the latter a difficulty arises because the metal to be welded also contains silicon and manganese, which have a great affinity for oxygen and thus lower the activity of this element in the molten metal. We shall get an upper limit for the hydrogen absorption of the molten metal if we only take into account that percentage of oxygen which on chemical analysis of the deposited metal is found in the form of FeO. On the other hand a lower limit for the hydrogen absorption will be found if the percentage substituted in eq 2 is the total analytically found oxygen content. However, the latter value should never exceed the saturation content of the molten metal at 1540° C, viz., 0.2% O. Even if more oxygen has actually been absorbed, we should never substitute a greater value since the surplus is not present in the dissolved state, whereas the quantity [% O] in the formula only refers to this state. As a matter of fact the metal absorbs more oxygen than corresponds to the solubility in molten iron if bare electrodes are used (the surplus as an oxide).

We have, basing ourselves on the experiments of Mallett and Rieppel,[6] substituted in the formula a value of 0.2 atm for the partial water vapor pressure in the arc atmosphere for all coated electrodes except the low-hydrogen one. For bare electrodes the water vapor content is at the utmost equal to that of the atmosphere, viz., only about 0.01 atmosphere. The same low partial pressure was entered in eq 2 for the low-hydrogen electrode. We shall discuss this later.

Table 1 gives both the total oxygen percentage and the oxygen present as FeO for the deposited metal of the above-mentioned types of electrodes. A third experimentally found content is given, viz., the hydrogen content of the deposited metal. Moreover, the table contains the lower limit of the hydrogen content calculated with the aid of eq 2 (see above).

Table 1—Hydrogen and Oxygen Contents of the Deposited Metal

	Experimentally found contents			*Lower limit of the hydrogen content according to formula (2)*	
Type of electrode	*Weight % O total*	*Weight % O as FeO*	*Weight % H*	*Weight % H*	*Cm^3 H_2 per 100 gr iron*
Bare	0.25	0.25	—	0.0002	2.5
"Dead-soft"	0.20	0.20	—	0.0010	11.5
"Mineral-coated"	0.12	0.04	0.0015	0.0013[5]	15
"Organic"	0.06	0.004	0.0020	0.0019	21
"Low-hydrogen"	0.03	0.001	0.0007	0.0006	6.5

Computation of an upper limit of the hydrogen content in the above-mentioned manner gives values for the two last types of electrodes that correspond to hydrogen pressures considerably higher than 1 atm. In these cases, therefore, calculation of an upper limit would have to be carried out in a slightly different manner. It would lead us too far to discuss the problem more extensively in this paper.

It will be noted that there is fair agreement between the experimentally found values and the calculated lower limits of the hydrogen content. This agreement is surprising since our calculations are but rough. We have not only based ourselves on an assumption which only holds good on approximation, viz., that a state of equilibrium is reached during welding, but—what is of

more importance—we have neglected two most important factors, viz., the release of a considerable quantity of hydrogen during the solidifying and cooling process and the absorption of a large quantity of hydrogen in excess of the above calculated lower limit under the influence of silicon and manganese present in the metal. The two faults in our computation apparently counterbalance each other. As a matter of fact the experimentally found hydrogen contents exceed the figure given in the table if the cooling process is extremely rapid, whereas abnormally slow cooling results in smaller hydrogen contents.

It is evident from Table 1 that the improvement of the quality of the weld metal by reducing the oxygen content was at first obtained at the cost of an increase of the hydrogen content. A high oxygen content is so unfavorable that bare electrodes are no longer used in most countries, although the welds produced by using these electrodes have a very low hydrogen content; dead-soft electrodes are only applied when a fine appearance of the bead is of more importance than its mechanical strength. All things considered, the two next types of electrodes, the mineral coated electrode (e.g., the Philips electrodes 50 and Contact 20) and the organic electrode e.g. the Philips 68 and Contact 18 are important improvements on the two preceding electrodes, but the hydrogen content of the deposited metal has risen to a relatively high level (especially if the organic electrode is used).

With basic electrodes, e.g., Philips electrodes 36 and 56, a weld can be made containing both little oxygen and little hydrogen. Therefore the use of these more expensive electrodes is often economically justified. We shall now proceed to a discussion of the way in which the favorable properties of these electrodes are obtained.

THE LOW-HYDROGEN ELECTRODE

In principle the oxygen content of the weld metal can be lowered by choosing an electrode coating that produces a slag containing no oxides at all or only very stable oxides. The use of iron oxides should be avoided in the first place. Good results can be obtained with a mixture of stable oxides and fluorides; their proportion in the mixture should be such that the quantity of nitrogen transmitted to the metal is also small.[7]

For the weld to have as low a hydrogen content as possible only little water vapor should be evolved by the coating during the welding process. At first sight, one would suppose that this requirement could easily be met by heating the electrodes before the welding process to a temperature that is high enough for all the chemically bound water to be driven out. However, such a thermal treatment tends to make most electrodes unfit for use since it considerably reduces the development of gas during the welding process; we have already observed that adequate evolution of gas is of primary importance. Moreover, the heat treatment as a rule reduces the mechanical strength of the coating to such a degree that the electrodes can no longer be transported.

However, all requirements can be met by: (*a*) using a coating containing a carefully chosen mixture of substances that evolve gases containing no hydrogen; (*b*) by a well-chosen thermal treatment of the electrodes before delivery. Since chiefly basic oxides are used in the coating, these low-hydrogen welding rods are often called basic electrodes.

Low-hydrogen electrodes manufactured and treated in the way described yield only very little hydrogen during the welding process; the water vapor pressure in the arc atmosphere is as low as in that of bare electrodes, viz., about 0.01 atm; according to eq 2 this corresponds to the low hydrogen content of the weld of 6.5 cm^3 per 100 gms of iron, already given in Table 1. The various difficulties caused by hydrogen are no longer observed if these electrodes are used.

USE OF LOW-HYDROGEN ELECTRODES

On the practical application of nonbasic electrodes it appears that their hydrogen content causes no difficulties at all in a great number of cases when normal unalloyed steel has to be welded. Low-hydrogen electrodes compare favorably, however, as soon as circumstances arise in which it is difficult for the hydrogen to escape from the metal, e.g., if the steel contains large quantities of sulfur or if the material is relatively thick (although in the latter case preheating the metal may sometimes prevent dangerously high hydrogen concentrations during the welding process when using nonbasic electrodes).

Care should be taken that low-hydrogen electrodes do not lose their good qualities by absorption of water vapor from the atmosphere by inadequate storage. Zoethout[8] tried out three simple methods to guarantee a sufficiently dry atmosphere in the storage room for low-hydrogen electrodes:

(1) Keeping the temperature in the storage room permanently at least 10° C higher than the outdoor temperature.

(2) Placing containers filled with hygroscopic substances in the storage room.

(3) Continously conveying dried and heated air into the storage place.

In practice each of these methods proved to be sufficient.

When welding in the open air, a storage place that comes up to one of the three above-mentioned requirements will in most cases not be available. The following procedure was therefore adopted when the large project shown in Fig. 2 had to be carried out in the Netherlands. The basic electrodes were delivered in boxes by the Philips welding rod factory to the unheated storeroom; these boxes were at once placed in tins which were sealed with gummed tape. Packed in this way the electrodes could be stored without any deterioration in quality. Naturally, after a box was opened, some

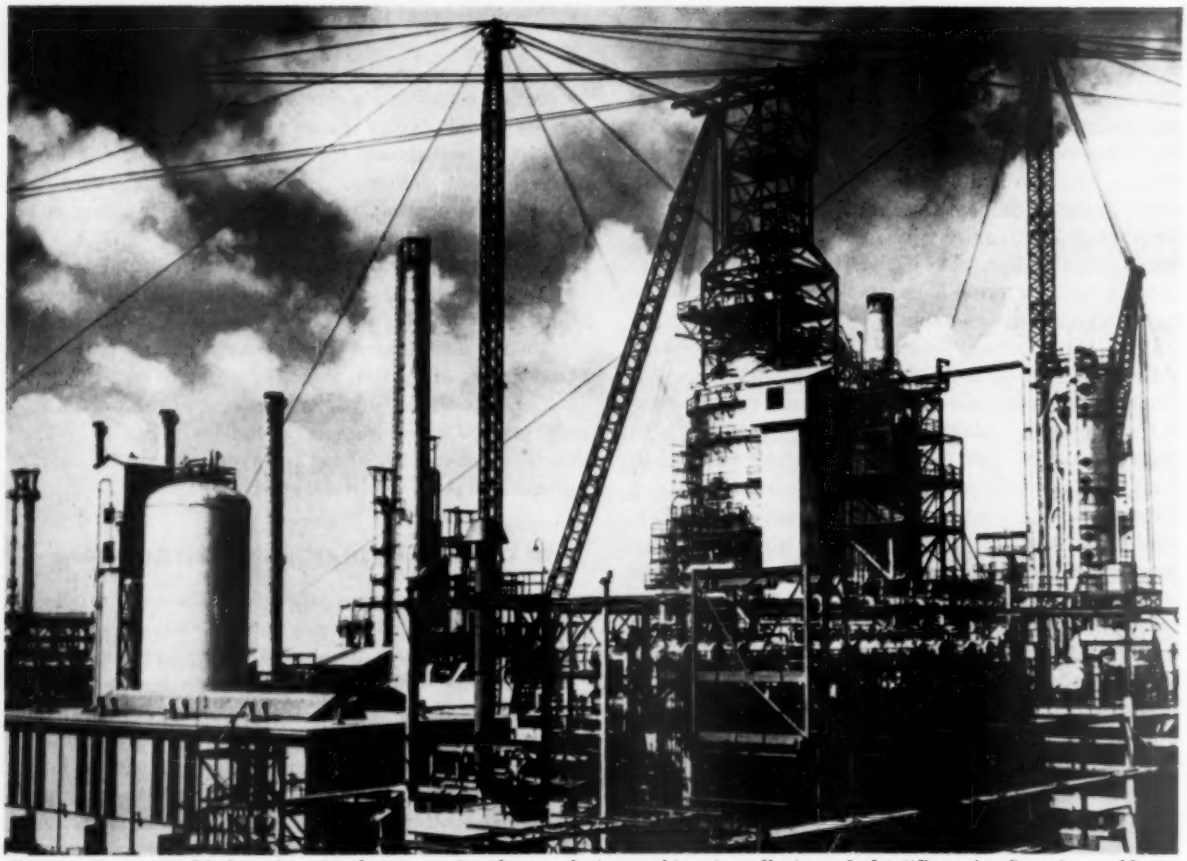

Fig. 2 A great welded project in the open air, the catalytic cracking installation of the "Bataafse Petroleum Maatschappij" at Pernis, a subsidiary of the Royal Dutch Company. This plant, with a capacity of 3500 tons high octane petrol a day, was completely welded with low-hydrogen electrodes type Philips 36. The number of electrodes used amounted to about 4 million

of the electrodes were in contact with the open air for several hours. However, the moisture absorbed by the welding rods during this period was never sufficient, not even when there was a thick fog, for poor hydrogen characteristics to develop during the welding process.

SUMMARY

Nowadays coated welding rods are almost exclusively used for electric arc welding. The coating should transmit little oxygen (and nitrogen) to the metal during the welding process, since otherwise bad quality welds are obtained. Suppression of the oxygen transmission causes absorption of large quantities of hydrogen if nonbasic welding rods are used. In unfavorable circumstances this may give rise to porosity and cracking of the weld. In order to decrease the hydrogen content, the welding rod should contain as little water as possible. Basic or low-hydrogen electrodes were developed to meet this requirement. For these electrodes to keep their favorable properties, they have to be stored in a special way.

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Quality Control of Resistance Welding by Statistical Methods

Ways of studying and interpreting variations falling within an acceptable pattern and discovery and elimination of variations falling outside this pattern

by J. F. Radford and R. K. Waldvogel

Summary

The function of American industry is to manufacture a product into which quality is built and maintained at a most economical cost which is consistent with a price available to the consuming public. Manufacturing losses, therefore, become an important phase of the over-all cost structure. Each year these types of costs are extremely high-dollar losses, and, a reduction in the high cost of quality represents one way of making a major savings in cost reductions. A major problem with industry has always been that experience dictates what the standards of a product should be without regard to facilities or capabilities of the process involved. Quality Control by statistical means is an invaluable tool of management which can be used to evaluate the quality standards, conformance to these standards and to determine what are equipment capabilities. Limits and practical applications of specifications may be established by applied control charts to determine the ability of a process to produce, consistent with actual job performance on the production line.

Manufacturing processes are always subject to some variation. Products whose physical or chemical properties are consistently held within close limits are manufactured under a stable system of chance causes. Variations within this pattern are inevitable and variations outside this pattern must be discovered and eliminated. The purpose of this paper is to discuss ways of studying and interpreting variation so that this may be accomplished.

Usual control of a product involves (1) 100% inspection, (2) lot checking, which eliminates the high cost of 100% inspection but which introduces many problems of sample errors and (3) the familiar patrol or process inspector whose duty is to discover defective work, or material at any point within his patrol area responsibility. Obviously 100% destructive inspection cannot be used on resistance welding operations, therefore, a plan must be rationalized which will utilize the techniques of lot inspection coupled with a sampling plan based upon the known laws of mathematical probability. If processes or operations are of continuous types and are difficult to control, the best means of control inspection may be through the use of the control chart. These will show trends in the control values toward whatever limits may have been established as to what is or is not an acceptable product.

In resistance welding a quality characteristic is established which usually revolves around strength of weld, therefore, tensile strength values are used for computable limits. However, spot spacing, diameter of weld spots, indentation, flash and other quality characteristics could be used in lieu of tensile strength if weld strength is not a factor of consideration.

INTRODUCTION

THE basis for modern statistical theory begins in the 18th Century with the discovery of the Normal Curve by the French mathematician, De Moivre; and, in addition, this curve was later independently derived by La Place and Gauss. An important modern day contribution to this science was the introduction of the control chart in 1924 by Dr. Shewhart and his associates of the Bell Telephone Laboratories; and, during World War II, the Office of Production Research and development of the War Production Board gave added impetus to this science by encouraging the adoption of statistical control in war plants. Although the use of statistical quality control is increasing daily, diligent search through welding literature published since 1940 has shown a surprisingly small amount of information is available which describes specific welding applications. A large percentage of the references given in the bibliography touch upon the use of quality control and control charts, but, at the same time, fail to give the reviewer explicit directions upon which to inaugurate a plant statistical control system. The authors wish their listeners to pursue this subject further by studying the references at the end of this paper. Statistical control is not being offered as a new tool which will solve all production problems, but is submitted as a useful method to maintain quality with resultant lowered inspection costs.

The subject matter consists of the following topics: (1) Frequency Distributions, (2) Normal Curve, (3) Standard Deviation and (4) "X" and "R" Charts.

BODY

The problem discussed here, as mentioned above, will

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be the institution of statistical control in a production-resistance welding department. The first step, if at all possible, is to attempt to standardize on the type of equipment to be statistically controlled. Similar electronic control panels, pressure application methods, and power supply systems should be used on all welders. In this way any "out-of-control" points or suspicious runs of plotted values on one side of the chart center lines may be analyzed and the fault corrected with a minimum of effort. The second step is to determine the critical value to be inspected and the method of measuring it. In the case of resistance welding the desired measured value may be the shear strength of the weld in pounds. It should be pointed out that additional tests may be used, e.g., the cross section macroetch test which is required in Class A welding to MIL-W Specifications. The shear strengths may be tested in the shop by the use of standard portable tensile testing machines located in the vicinity of the welding equipment as shown in Fig. 1.

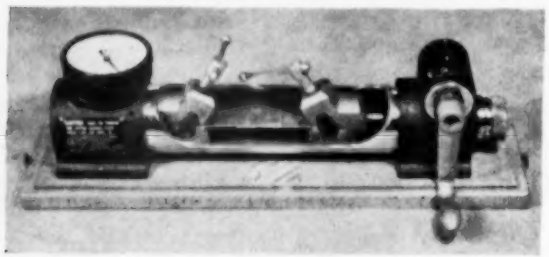


Fig. 1 Portable tensile testing machine

It should be of great interest for those of you who are contemplating obtaining military contracts, involving resistance welding, that the MIL-W Specifications permit and even encourage the use of statistical control. The test data derived from machine qualification, which determines the welding capacity of the equipment, and from process certification, which tabulates the control settings for each production pileup, must (for aluminum) have 90% of the results lying within plus or minus 12½% of the average and the remainder of the data must lie within plus or minus 25% of the average value. Class "A" welding of critical assemblies under the military welding specification also carries a restriction under which the ratio of the range to the average of a set of three hourly samples must not exceed 35% variation. These rules are designed to maintain uniform and consistent strengths rather than very high weld strengths. These provide for the gathering of data by welding and testing three tension shear specimens each hour.

In progressing to a description of the control chart, a few of the terms used in its explanation are described below:

The first one is the frequency distribution which is a table listing the frequency of cases in each of a series of numerical classes. See Fig. 2 which shows two examples of a frequency distribution, the histogram and the frequency polygon. The purpose of a frequency tabulation is: (1) to condense a mass of data into convenient form, (2) to show the average value and the variability of the data and (3) to compare the observed data with certain standard distributions, in this case, the normal curve.

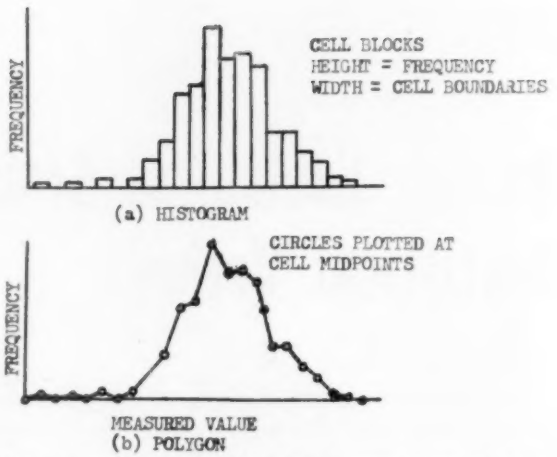


Fig. 2 Two methods of graphical presentation of a frequency distribution

The normal curve is an idealization of the frequency polygons described above and is shown in Fig. 3. The normal curve often fits practical distributions very well, but the observed distribution should be reasonably symmetrical about its vertical centerline. Experience shows that in a great many cases, as a process is brought into good statistical control, the frequency distribution of measurements becomes "normal," and, quite often, the normal curve can be used as a first approximation before the collection of actual data. Figure 4 shows the plotted points of an aluminum spot weld qualification test made under MIL-W-6860 Specifications with a smooth curve drawn through the data. The machine on which this qualification was made is shown in Fig. 5. It is of the 3-phase frequency converter aircraft type, with a 100-kva rated capacity.

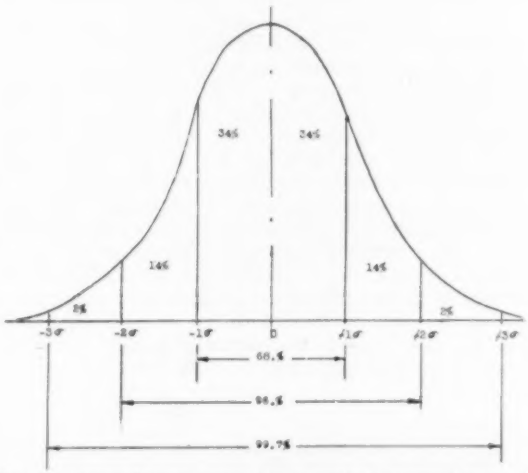


Fig. 3 Approximate areas for a typical normal curve for frequency distribution

To return to a further explanation of the normal curve (see Fig. 3) the Greek letter σ (sigma) is used to represent a term called the standard deviation and this may be defined as the average of the scatter of the plotted values about the vertical centerline and is a measure of dispersion. To delve further into the use of this term is beyond the scope of this paper. However, it should be firmly noted that the areas enclosed by plus or minus 1, 2 and 3σ (sigma) lines represent the per cent of the area under the curve. For example, the area surrounded by the plus or minus 3σ (sigma) boundaries is 99.7% of the total under the curve and means that there are only three chances out of 1000 that points falling outside of these lines are "in control." With the foregoing information giving the desired value to be tested (the tension shear coupon) and the method of collecting data (hourly samples), the control charts are ready to be described and to be applied, using actual shop shear strengths in a practical example.

Control charts are a graphical record of quality, upon which are placed a central line and a pair of control limit lines on either side of the centerline. The control limit lines assist in determining the importance of the quality variations about a certain level and are so placed that plotted points falling outside of the limit lines indicate a cause of variation which should be investigated. Before the principle of control limits is described, a short explanation of specification limits is given. These limits are the values given in the product specifications and are the extreme permissible boundaries of quality which will insure adequate performance of each individual unit of a product. This, of course, should not be confused with statistical $\bar{X}$ limits, since these are averages of the lot, whereas, the specification limits apply to individual parts or assemblies only.

Variations of quality in a product can be attributed to numerous causes and may be classed in one of two groups: (1) a variation that deserves no attention and (2) a variation attributed to an assignable cause, which should be segregated and eliminated. The control chart can only indicate the time and location of the trouble; after this has occurred, it is the responsibility of the engineering or maintenance departments to correct the difficulty. When a state of control appears, but the manufacturing process is not capable of producing assemblies within the specification limits, two courses of action are open: (1) change the manufacturing process or (2) modify the specification limits. Some of the advantages of a state of control are: a decrease in the variation between individual products and a reliable record upon which to base a request for specification changes.

Major functions of the control chart are the factual record as to whether a state of control exists and the attainment of production quality control. When the data from at least 25 subgroups fall within control limits constructed as outlined in Table 1, it may be safely assumed that a state of control is in force. See Fig. 6

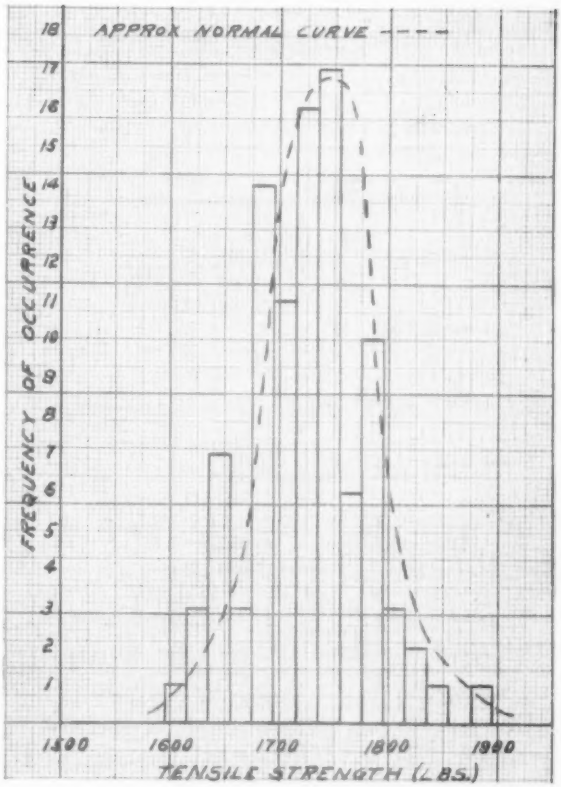


Fig. 4 Aluminum qualification histogram (0.091 in. thick 52S-H32)

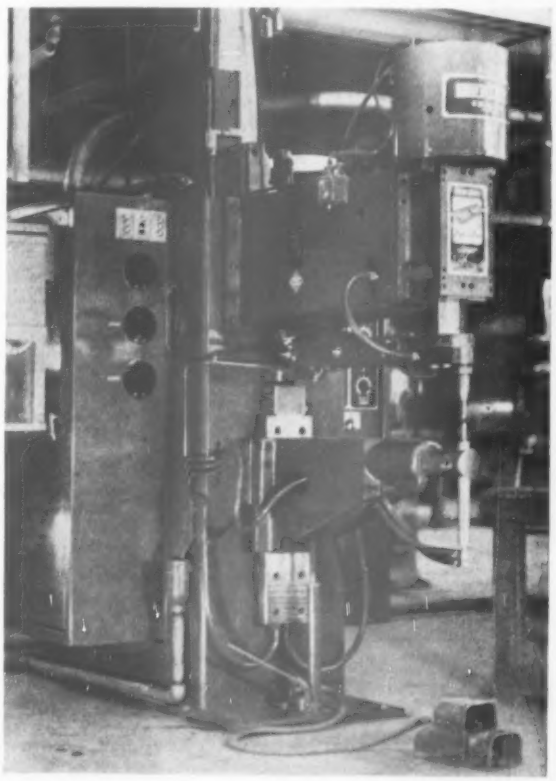
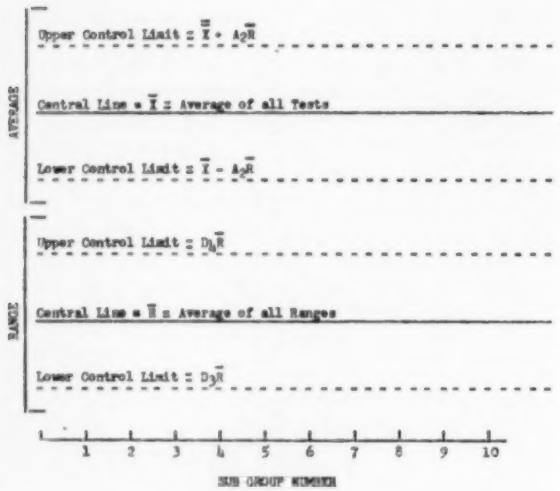


Fig. 5 Frequency converter aircraft welder

Table 1—Instructions for Constructing Control Charts for Average and Range


AVERAGE
Upper Control Limit = $\bar{\bar{X}} + A_2\bar{R}$
Central Line = $\bar{\bar{X}}$ = Average of all Tests
Lower Control Limit = $\bar{\bar{X}} - A_2\bar{R}$
RANGE
Upper Control Limit = $D_4\bar{R}$
Central Line = $\bar{R}$ = Average of all Ranges
Lower Control Limit = $D_3\bar{R}$
1 2 3 4 5 6 7 8 9 10
SUB GROUP NUMBER

ORDER IN CONSTRUCTION OF CONTROL CHART

1. Maintain each subgroup of observed values as a separate unit. The items of each subgroup should have some important common element, i.e., produced at the same time or from the same machine and should be of identical size.
2. For each subgroup, add the observed values and find their average ($\bar{X}$, designated as X bar).
3. Compute the grand average of all the observed values by adding all results and dividing by the total number. This is indicated by the sign $\bar{\bar{X}}$ (X double bar).
4. In each subgroup, subtract the smallest value from the largest value. The difference is specified by the letter R (Range).
5. Compute the average of all the R values. This result is shown by the sign $\bar{R}$ (R bar).
6. On suitable graph paper, lay out an area for an $\bar{X}$ chart and another section for an R chart. With vertical scale (ordinate) at the left for $\bar{X}$ and R and with a horizontal scale (abscissa) for subgroup number. Plot solid horizontal lines to represent $\bar{\bar{X}}$ (Step 3) and $\bar{R}$ (Step 5).
7. *Placing the Control Limits.* On the $\bar{X}$ chart, draw two horizontal dotted lines at $\bar{\bar{X}} \pm A_2\bar{R}$; and on the R chart draw two horizontal lines at $D_3\bar{R}$ and $D_4\bar{R}$. The factors A_2, D_3 and D_4 are based on N, the number of observations in a subgroup, see Table 2. Note that when $N = 6$ or less, $D_3 = 0$, therefore, R charts for the application described in this paper will have a lower limit equal to zero.
8. Plot the computed subgroup values for $\bar{X}$ on the average chart and the computed values for $\bar{R}$ on the range chart.
9. *Chart Interpretation.* Plotted data falling outside of the control limits can be indicative of the need for corrective action.

which shows the physical features of a chart with points "in control" and "out of control."

In attaining and maintaing control of quality, a continuous record of manufacturing product quality is kept in order to discover any assignable cause of variation as soon as it appears. A control chart is established as follows: an experimental standard level of quality is derived from 25 subgroups as noted above and/or this may be based on experience and/or vendors and governmental specifications, such as the previously mentioned MIL-W-6860 for welding of aluminum. The values derived from sample testing should be plotted as soon as the results are determined. If these values are outside of the control limits, the cause should

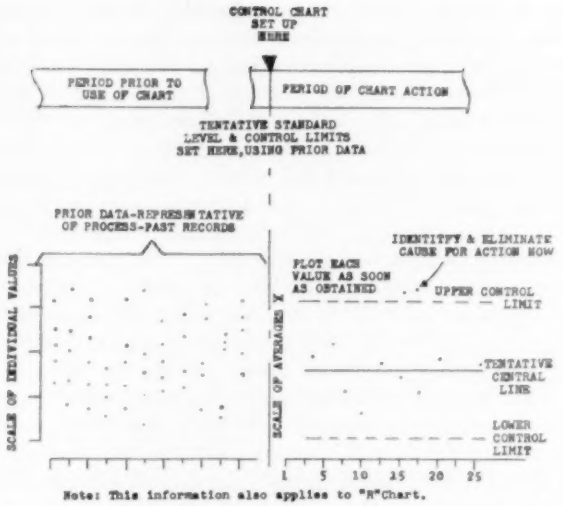

CONTROL CHART SET UP HERE
PERIOD PRIOR TO USE OF CHART
PERIOD OF CHART ACTION
TENTATIVE STANDARD LEVEL & CONTROL LIMITS SET HERE, USING PRIOR DATA
PRIOR DATA-REPRESENTATIVE OF PROCESS-PAST RECORDS
IDENTIFY & ELIMINATE CAUSE FOR ACTION NOW
PLOT EACH VALUE AS SOON AS OBTAINED
UPPER CONTROL LIMIT
TENTATIVE CENTRAL LINE
LOWER CONTROL LIMIT
SCALE OF INDIVIDUAL VALUES
SCALE OF AVERAGES X
1 5 10 15 20 25
Note: This information also applies to "R" Chart.

Fig. 6 Features of the control chart as used for analyzing data or for controlling quality

then be investigated and eliminated. This method of control is practically self sustaining and automatically assures the production of economical assemblies. The effective use of the control charts, as outlined previously, is dependent upon the prompt discovery and removal of the manufacturing difficulty. This is primarily a responsibility of the technical personnel involved and should be accomplished through cooperation between the engineering and statistical control groups by persons who have at least a rudimentary knowledge of the others' special activities.

In the actual construction of the control chart, Tables 1 and 2 outline the steps and give multiplication factors the use of which will best be illustrated by the example given later. The exact spacing of the upper and lower control limits cannot be stated as an inflexible rule but is more or less a result of existing conditions. Generally speaking a good rule to follow is to place the control limits at a plus or minus 3σ (standard deviation) distance above and below the chart centerline. This will be computed in the example. This proposed spacing attempts to provide a balance between two types of

Table 2—Factors for Computing Control Chart Lines—Small Samples

Number of observations in sample N	*Factors for control limits*		
	Charts for averages, A_2	*Charts for ranges*	
		D_3	D_4
2	1.880	0	3.268
3	1.023	0	2.574
4	0.729	0	2.282
5	0.577	0	2.114
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777
11	0.285	0.259	1.744
12	0.266	0.284	1.717
13	0.249	0.308	1.692
14	0.235	0.329	1.671
15	0.223	0.348	1.652

errors, viz., (1) looking for trouble that does not exist and (2) not looking for trouble that exists.

The control chart data used in this paper was derived from a 3-phase machine of the type shown earlier. The welding to be described is the spot welding of 0.040- to 0.040-in. thick 52S-$^1/_4$H aluminum alloy, since this is a common pileup in the industry. This material is chemically cleaned by placing it in a nonetch precleaner for 5 min to remove surface soil and to establish a "no water break" surface. This is followed by a cold-water rinse, then a 5-min immersion in a standard proprietary chromic acid oxide removal bath, succeeded by a cold-water rinse and an air dry. This procedure will give surface resistance readings from 0 to 50 microhms with a holding power of up to 48 hr. Welder control settings include 1000 lb tip force, 1 cycle weld time, 3 cycles current decay and approximately 51,000 secondary amperes, using No. 2 Morse Taper Class I alloy electrodes with a 3-in. spherical radius face. The surface resistance analyzer used to check the cleaning solutions is shown in Fig. 7. It should be noted that all shop personnel handling aluminum during the cleaning and welding operations must wear clean cotton gloves.

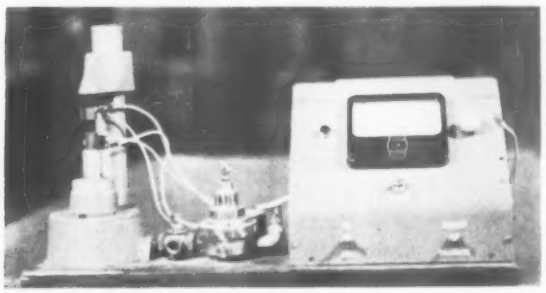


Fig. 7 Surface-resistance analyzer

A suggested control chart data sheet, Fig. 8 tabulates the test results and gives the derivations for the limit lines shown on the suggested control chart record, Fig. 9. Each subgroup size (N) is equal to 3, with the range being the difference of the maximum and minimum values and the average found by dividing 3 into the sum of the values. Each average value and range value is plotted on its respective chart, with the points outside the limits calling for immediate attention. It must be again noted that the chart construction was derived by using the equations printed thereon, with X and R values obtained from previous testing.

CONTROL CHART DATA SHEET

PRODUCT Case Assembly MATERIAL .040"-.040"-52S-¼H Alclad

CHARACTERISTIC Spot Weld Shear Strength ORDER NUMBER

UNIT OF MEASUREMENT Pounds DEPARTMENT NUMBER 963

SPECIFICATION NUMBER MIL-W-6560 SAMPLES 3 PER hour

SPECIFIED LIMITS MIN. 370 AV. 420 MACHINE 4607

DATE Sept 1952 INSPECTOR Fred Roberts

SUB GROUP NUMBER	1	2	3	4	5	6	7	8	NO.	$\bar{X}$	R
a	575	575	525	525	610	575	525	600	1	525.0	75
b	500	525	600	600	525	600	525	495	2	563.3	65
c	500	590	575	625	625	525	600	580	3	566.7	75
TOTAL	1575	1690	1700	1750	1760	1650	1650	1675	4	583.3	100
AVERAGE $\bar{X}$	525	563.3	566.7	583.3	586.7	550	550	558.3	5	586.7	100
RANGE R	75	65	75	100	100	75	75	105	6	550.0	75
DATE & TIME									7	550.0	75
SUB GROUP NUMBER	9	10	11	12	13	14	15	16	8	558.3	105
a	480	500	510	500	535	525	625	525	9	501.7	145
b	500	500	650	525	600	575	550	600	10	525.0	75
c	525	575	590	630	540	475	625	500	11	583.3	140
TOTAL	1505	1575	1750	1655	1655	1575	1800	1625	12	551.7	130
AVERAGE $\bar{X}$	501.7	525	583.3	551.7	551.7	525	600	541.7	13	551.7	85
RANGE R	45	75	140	130	85	100	75	100	14	525.0	100
DATE & TIME									15	600.0	75
CALCULATION OF LIMITS									16	541.7	100

$A_2\bar{R} = 91.05$ TOTAL 8863.4 1420

$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$; $LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$

554 1.023x89.645 ; 554-1.023x89.463

$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$

2.574x89.229 0x89.0

$\bar{\bar{X}}$=554 $\bar{R}$=89

NOTES:

Fig. 8 Suggested control chart data sheet

PRODUCT Case assembly MATERIAL .040"-.040"-52S-¼H Alclad

CHARACTERISTIC Spot Weld Shear Strength ORDER NUMBER

UNIT OF MEASUREMENT Pounds DEPARTMENT NUMBER 963

SPECIFICATION NUMBER MIL-W-6560 SAMPLES 3 PER hour

SPECIFIED LIMITS MIN. 340 AV. 420 MACHINE 4607

Q. C. ENGINEER R B Woodward INSPECTOR Fred Roberts

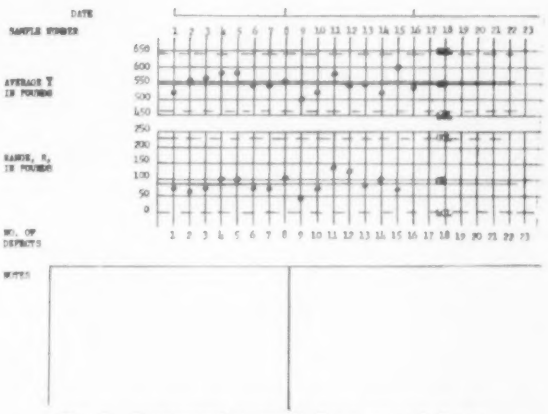


Fig. 9 Suggested control chart record sheet

CONCLUSION

To correct a common misconception, it should again be emphasized that specification limits cannot be used on the control chart for averages, since it is the individual article which must meet the specification, not the average of a subgroup as used on the $\bar{X}$ chart. Control charts for individuals are less efficient than the average chart, since the former are relatively insensitive to shifts in the process average. The material introduced in this article is derived from actual weld sampling and is presented to give a case study of the manner in which data may be accumulated for introduction of a control program.

The benefits which management may expect to gain from an applied scientific quality control program will generally fare into those of reduction of costs and losses,

those of design and method improvement and improvement of product quality. Experience will indicate that any quality control program must have the wholehearted support of top management and the line organization wherever applied to assure its success. It must be remembered that quality control is no substitute for sound experience and good management practice. Resistance welding has many variables and these must be carefully screened in a scientific manner to avoid wrong conclusions. Uncoordinated activities in approaching production problems are only conclusive in that they produce greater uncertainty and confusion. By using a plan based upon sound quality control principles the uncertainty may be minimized and practical application will prevent the production of defective pieces with resultant cost savings.

ACKNOWLEDGMENT

The authors' appreciation is extended to R. W. Duncan, Works Manager, for permission to present this paper.

In addition, references 1, 2, 3 and 4 have been used in the preparation of this discussion.

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(*Continued on page 551*)

Aft Frames

RYAN has attained a high production rate on one of the most difficult-to-build structures used in General Electric J-47 jet engines. Labeled "aft frames," these components are undoubtedly the most complex stainless steel products which Ryan has made.

In spite of the reams of publicity which have been written about jet power plants, few know what an aft frame is or realize its importance to the function of a jet engine. This is not surprising. The limelight has been hogged by sizzling combustion chambers, whirling turbine wheels and flaming afterburners. With no moving parts and a prosaic name, the aft frame seems to be consigned to anonymity. Yet, it is one of the most important structures of the engine and merits top consideration because of the amazing amounts of welding and machining which are incorporated within its skeletonlike contours.

Actually, the aft frame may be thought of as the "backbone" of the "hot end" of the jet engine. It is the structural member which holds the seething combustion chambers, transition liners and turbine and compressor cases together. It contains the housings which support two main bearings of the high-speed turbine-compressor shaft. This is a major assignment because the alignment of these bearings is critically close. Through the aft frame, air cooling and lubrication are provided for the rotor bearings.

Each aft frame contains about 150 ft of high-quality welding, 220 precision-drilled or tapped holes and more machining than any other Ryan-made component. Coupled with these startling requirements are a list of manufacturing tolerances which are among the most exacting encountered in the industry.

In configuration, the aft frame consists of a slightly tapered, cylindrical barrel to which are attached a number of heavy-gauge, machined flange sections. Near the aft end of the barrel a large, circular burner plate is slipped on and welded. By means of eight flanged eyelets in its periphery, this plate positions the combustion chambers and holds them in alignment. The aft frame is bolted to the compressor case, in front, and to the turbine case, at the aft end. The high-speed turbine-compressor shaft passes through the barrel of the aft frame and is supported by two main bearings which are housed within its interior.

The keywords of the aft frames' function are strength and precision. Because all of the other "hot end" components depend upon the aft frame for their carefully balanced performance, it must be extremely strong and perfectly dimensioned. To obtain these features every innovation in design, fabrication and inspection techniques has been utilized.

All component parts for the aft frames are pressed out in steel dies with large presses. This fast method provides exact-size parts and eliminates practically all handwork such as sawing and filing. In the case of the heavy burner plate assembly, nearly all of the 600-ton capacity of the big Warco press is used to blank out this piece.

A barrel is rolled into shape and welded along its longitudinal seam on automatic inert-gas welding machines. A series of curved steel strips are seam welded into the interior of the barrel to make it a double-walled affair which is extra strong and monocoque in design.

All parts of the aft frame are joined together by precision welding methods with no other means of attachment being used. Sixty-four feet of electric seam welding are used to form the barrel alone. More than 75 ft of manual metallic arc welding is employed to attach the five major flanges to the barrel and join other details.

Welding quality requirements are high.

Fig. 1 Close-up of a Ryan aft frame being arc welded along the seam where the large burner plate is attached to the tapered barrel of the aft frame. More than 150 ft of high quality welding is made in each aft frame structure

Ryan Aeronautical Company, San Diego, California.

Fig. 2 The tapered cylindrical barrels of the aft frames are seam welded on Taylor-Winfield seam-welding machines which have wheel electrodes positioned to perform longitudinal welds. These machines attach the stainless steel strips to the interior of the barrels giving them a double-wall strength of monocoque design

The large circumferential welds must be accomplished, manually, with weld widths controlled within $^1/_{16}$ in. and parent metals penetrated to at least 20% of thickness.

Special welding problems are posed by the widely varying thicknesses of the metals being joined. Seams are made between metals with such difference in thickness as $^1/_{16}$ in. to $^3/_8$ in. This requires extra care in order to obtain correct penetration into the metals and to prevent undue distortion and cracking caused by the different rates of heat dissipation.

Because they are large, contain many mating surfaces and incorporate close dimensions, the aft frames require a record-breaking number of machining operations. Most surfaces must be finished to a smoothness of 63 rms microinches. Drilled and tapped holes have to be centered within 0.010 in. of true location. Concentricity and squareness specifications demand that specified surfaces must be perpendicular to others within 0.0003 in. per inch. Certain diameters are held within a plus or minus 0.001 in.

These extensive machining operations have necessitated the use of an array of large, expensive machines which are the most elaborate that Ryan has ever assembled for a production project. Substantial numbers of vertical turret lathes, gap lathes, radial arm drills, boring mills, multiple drilling machines and tapping machines are employed as well as a number of specially designed, single-purpose tools.

To machine, automatically, three large flanges in one setup, Ryan has installed a unique Excello boring machine which has been designed and built for this particular task. The most expensive single-purpose machine in the plant, this $65,000, 20-ton tool takes only 15 min to perform the machining which would otherwise require 4 hrs. With three separate heads, equipped with thirteen carbide-tipped cutters, the giant goes into action at the press of a push button. While the aft frame remains firmly clamped, the cutting heads rotate and move into the work to machine both end flanges and the interior bearing housing. Concentricity of the machined surfaces is held within 0.002 in.

One of the difficult machining assignments for production of the aft frame was the cutting of the eight combustion chamber eyelets which rim the burner plate. These flanges require boring, turning, facing and undercutting within tolerances of 0.005. To do this work on boring mills would have taken 2 days per frame and tied up costly machines. Ryan devised a special boring fixture powered by standard radial arm drills, which accomplishes the work in 2 to 3 hr. Containing four sets of rough and finish cutters, these fixtures make a series of eight machining operations in one continuous sequence without supervision.

Another interesting machine tool which saves countless hours of production time is the new Natco multiple-splindle drilling machine which Ryan uses to drill the 160 precision bolt holes in the burner plate, adapter flange and bearing housing. Dwarfing all other drilling machines at Ryan by its size and power, this behemoth cuts a 3-hr drilling job down to 15 min. Powered by a 25-horsepower electric motor, the Natco drills forty holes at a time.

After machining, the aft frames are cleaned of all chips, turnings and other extraneous material by vibration. They are clamped to a base which is fitted with two cylinders and oscillating pistons actuated by compressed air. The frames are vibrated at high frequency to shake out all foreign matter. Soil and grease are removed by immersing them in a trichlorethylene vapor bath.

An essential part of the production procedure for building aft frames is heat treating. Substantial amounts of residual stress are locked up in the components as a result of the extensive forming, welding and machining which they undergo. To remove these stresses, the aft frames are heated, electrically, in a closed General Electric furnace. Heating and

cooling cycles are carefully regulated for a 16-hr period to remove all traces of tension so that the structures will maintain perfect alignment in jet engine service. The furnace is fed a controlled atmosphere to prevent oxidation of the hot metal during the heat-treating process.

After completion, the aft frames are shipped from Ryan to the General Electric Company plant at Evendale, Ohio. Here, they are mated with other Ryan-built assemblies, such as combustion chambers, afterburners, exhaust cones and transition liners, and assembled into J-47 jet engines.

General Electric has devised a novel method of assembling the engines in a vertical position. This provides for better alignment of the 12-ft long jets by avoiding even slight sag in the components due to weight. It saves a good deal of valuable floor space and permits faster assembly of the units because more of the engine is accessible to work on.

Hard Facing Pump Parts

Sprayed-on, fusion-bonded hard surfaces prolong life, cut maintenance costs of oil producing and refining equipment

PUMP parts hard faced by the Sprayweld process, developed by Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich., are lasting from 4 to 8 times as long as new unprotected parts in oil producing and refining equipment. The increased life of these parts is the result of extreme wear and corrosion resistance of the fusion-bonded Colmonoy No. 6 Alloy surface that is applied by the process in thicknesses from 0.030 to 0.045 in. The alloy surface has the additional advantage of a low coefficient of friction that reduces packing wear and cuts downtime for pump repacking.

Maintenance costs for pump components are further reduced because the Sprayweld surface can be renewed by the same process after extended periods of operation, thus avoiding the purchase of new parts.

Figure 1

THE SPRAYWELD PROCESS

The first step in Spraywelding a new or reclaimed pump part like a plunger is to turn down the diameter of the surfaces to be hard faced in a lathe, so that a final thickness of alloy of about 0.045 in. remains on the part after processing. Then the plunger is grit blasted with steel grit to provide a surface to which the sprayed-on alloy will adhere before fusing.

The plunger is next chucked in a lathe and rotated while the alloy is applied by spraying with the Spraywelder pistol (see Fig. 1) mounted in a holder attached to the lathe tool post. The pistol is machine-traversed back and forth across the rotating workpiece until a uniform coating about 0.010 in. thicker than the finished OD dimension is applied. The light weight and maneuverability of the Spraywelder pistol permits manual spraying operations to be done if desired.

A fusion-bounded, nonporous welded overlay is achieved in the next step, when the pistol unit is fed out of the way and the part is rotated in the lathe under an oxy-acetylene torch. Warpage of the plunger in this step is practically eliminated because only sufficient heat to fuse the thin overlay is necessary.

The final step in preparing a Spraywelded pump plunger before installation in pumping equipment is to finish grind the diameter of the hard-faced surface to the correct dimension. In applications where a ground finish is not required, the surface can be turned with a carbide tool.

PROPERTIES OF THE NICKEL-CHROME BORIDE SURFACE

The Colmonoy No. 6 Alloy applied by the Spraywelding process is in powder form. It is a nickel base alloy containing chromium, boron and nickel and has a Rockwell C hardness from 56 to 61. It is nonmagnetic, has a specific gravity of 7.80 and melts at 1900° F.

Among its outstanding physical properties are extreme resistance to abrasion, corrosion and galling. It has good impact resistance and excellent red hardness. While in its plastic range from 1850 to 2050° F, No. 6 will bond to steels, stainless steels, some cast irons and some copper alloys without flowing or losing its shape.

the AMERICAN WELDING SOCIETY

activities • related events

Nominations for Officers, Board and Nominating Committee Members

The Nominating Committee of the AMERICAN WELDING SOCIETY selected the following officers and directors for the term commencing October 1953:

President—F. L. Plummer, Director of Engineering, Hammond Iron Works, Warren, Pa.

First Vice-President—J. H. Humberstone, Vice-President, Air Reduction Co., Inc., New York, N. Y.

Second Vice-President—J. J. Chyle, Director, Welding Research, A. O. Smith Corp., Milwaukee, Wis.

Treasurer—R. S. Donald, President, R. S. Donald, Inc., New York, N. Y.

Directors-at-Large—J. W. Mortimer, Engineer, Whitlock Mfg. Co., Elmwood, Conn.; C. P. Sander, General Superintendent, Consolidated Western Steel Co., Los Angeles, Calif.; Hal Savage, President, Arizona Welding Equipment Co., P.O. Box 666, Wichita 1, Kansas; R. L. Townsend, Owner, Tweco Products Co., Wichita, Kan.

The District Nominating Committees of the AMERICAN WELDING SOCIETY selected the following District Vice-Presidents and District Representatives on the 1953–54 National Nominating Committee:

District Vice-Presidents—No. 1 (New York and New England), C. E. Jackson, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y.; *No. 3* (Southern), A. E. Pearson, Ingalls Iron Works, Birmingham, Ala.; *No. 5* (Mid-Western), J. B. Welch, Cutler-Hammer, Inc., Milwaukee, Wis.; *No. 7* (Western), C. M. Styer, Pacific Car & Foundry Co., Seattle, Wash.

District Representatives on 1953–54 National Nominating Committee—*No. 1* (New York and New England), L. H. Hawthorne, Revere Copper & Brass, Inc., Rome, N. Y.; *No. 2* (Mid-Eastern), A. M. Setapen, Handy & Harman, New York, N. Y.; *No. 3* (Southern), A. A. Holly, Arnold V. Walker Shipyard, Pascagoula, Miss.; *No. 4* (Central), T. J. Crawford, Consulting Engineer, Berkley, Mich.; *No. 5* (Mid-Western), T. B. Jefferson, *The Welding Engineer*, Chicago, Ill.; *No. 6* (Mid-Southern), W. J. Snider, Black, Sivalls & Bryson, Inc., Kansas City, Mo.; *No. 7* (Western), C. W. Johnston, Victor Equipment Co., Inc., Los Angeles, Calif.

AWS National Spring Meeting, Houston, Tex., June 16–19, 1953

SPECIAL EVENTS

Thursday Afternoon and Evening, June 18th—Trip and Dinner

Trip to San Jacinto battleground by boat via ship channel or by bus at individual's option. Bus trip will pass refinery and chemical plants on Ship Channel. Trip starts 2:30 P.M. Tour of battleground, San Jacinto Monument and Museum and Battleship *Texas*. Terminates at famous San Jacinto Inn at 5:30 with Fellowship Hour provided with relaxing refreshments.

Captain's famous seafood dinner served at 7:00 P.M. Transportation back to Shamrock provided by bus at 9:30 P.M. Cost of trip $7.50 including transportation, cocktails and dinner.

Plant Visits:

TUESDAY, JUNE 16th

A. O. Smith-Sheffield Pipe Mill
Leave Shamrock Hotel by bus
1:00 P.M.

WEDNESDAY, JUNE 17th

Hughes Tool Co.
Leave Shamrock Hotel by bus
1:00 P.M.

Ladies Entertainment:

TUESDAY, JUNE 16th

2:15 P.M. Tea and fashion show at Sakowitz Bros.

WEDNESDAY, JUNE 17th

10:00 A.M. Tour of Houston

THURSDAY, JUNE 18th

9:30 A.M. Tour Shamrock kitchens
2:00 P.M.* Bus or boat to San Jacinto Battleground and Monument and Battleship *Texas*
6:00 P.M.* Highball Hour — San Jacinto Inn
7:00 P.M.* Dinner—San Jacinto Inn (return to Shamrock by bus. Arrive 11:00 P.M.)

Dinner (combined with Ladies Entertainment)

THURSDAY, JUNE 18th

6:00 P.M.* Highball Hour — San Jacinto Inn
7:00 P.M.* Dinner—San Jacinto Inn (return to Shamrock by bus)

* All one activity. Tony Martin Orchestra at Highball Hour and Dinner.

Welding & Allied Industry Exposition

The AMERICAN WELDING SOCIETY'S Exposition being held June 16th through June 19th at the Shamrock Hotel Hall of Exhibits in Houston, Tex., by present indications, is an outstanding success. Key welding interests from all over the country will attend this gigantic all-welding exhibit.

Information from the more than 65 exhibitors—manufacturers of products for the welding and allied industries—indicates a wide variety of products will be exhibited many in actual use. Products shown will include: aluminum alloys and fluxes, silver brazing flux, stainless steel solder, positioners, contour and radius markers, centering heads, welding rods, electrodes, castings, miscellaneous brazing alloys, electrode holders, weld cleaning tools, magnetic particle inspection instrument, arc-welding equipment, welder caps, lighters, and chains, portable industrial X-ray units, regulators and torches.

Here under one roof are demonstrated the products of many manufacturers who regularly sell products for welded fabrication, weldments, welding processing, gas cutting, brazing, finishing, tooling, gaging, testing, stress relieving, X-raying, servicing and handling.

Action-type demonstration displays are presented by Adams Alloy Co., All-State Welding Alloys Co., Dockson Corp., Handy and Harman, Hobart Brothers, J. M. Ragle Industries, Sonoflux Corp. and Stoody Co.; a full-length film on arc-welding electrode manufacture by Alloy Rod Co.; and many new and improved products are scheduled for initial showing at this AMERICAN WELDING SOCIETY sponsored show.

THE SYMBOL OF

QUALITY WELDS

WIRE FOR WELDING

- STAINLESS STEELS
- ALLOY STEELS
- ALUMINUM
- BRONZES
- SPECIAL ALLOYS

WELDSPOOL

the ONLY chemically processed precision spooled electrode wire designed and suitable for ALL TYPES—ALL MAKES inert gas welding equipment

WELDBEST

DC
AC/DC

the covered electrodes with BUILT-IN-QUALITY

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"WELDBEST" Cutting Rod Holder
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The American Creed

The United States of America is one of the few countries in this turbulent period that is dedicated to the premise that Life, Liberty and Property coupled with the individual's right to earn a living shall remain inviolate as the privilege of every citizen or group of citizens. This is the basis of free enterprise and unrestrained competition.

We of WELDWIRE initiated an experiment in free enterprise that has been nurtured by the welding industry and in particular by its related technical societies, various suppliers and our respected competition. We take this opportunity, as a fledgling in our industry, to thank all of those who have in some way contributed to our development; for if free enterprise and unrestrained competition in the American tradition was to be stifled or unjustly restricted, or scientific achievement was to be completely controlled; our government would no longer be dedicated to the ideals of freedom.

To those who would dare thwart these freedoms, externally or internally, frustration can only occur.

WELDWIRE COMPANY, INC.

PERSONNEL

Jerome Strauss to Deliver H. W. Gillett Lecture

Jerome Strauss, Vice-President, Vanadium Corporation of America, New York, will present the second H. W. Gillett Memorial Lecture. Mr. Strauss has selected the subject, "Micrometallurgy."

This lecture—first presented at the Fiftieth Anniversary Meeting of the ASTM—is jointly sponsored by the American Society for Testing Materials and Battelle Memorial Institute. It commemorates Horace W. Gillett, one of America's leading technologists and metallurgists and the first Director of Battelle. Each year it will cover subjects pertaining to the development, testing, evaluation and application of metals.

The 1953 ASTM Annual Meeting will be held in Atlantic City during the period June 29th through July 3rd, and on Tuesday afternoon, June 30th, Mr. Strauss will deliver the H. W. Gillett Lecture. The 1953 lecture will involve the significance and effect of very small and in some cases minute quantities of elements on various metals and alloys.

Brown New President of IAA

W. A. Brown, Jr., President and General Manager of The Liquid Carbonic Corp., was elected President of the International Acetylene Assn. at its 53rd Annual Convention held in Atlanta, Ga., on April 13th, 14th, and 15th.

The International Acetylene Assn., which is one of the oldest technical associations in the world, was organized in 1898 for the purpose of developing broader and more generally useful applications for calcium carbide, acetylene gas and allied products, and to disseminate technical information concerning such developments. This objective is carried out by the Association through its technical publications, its cooperation with other technical societies, its work with regulatory bodies and its annual convention.

A. F. Davis Elected President of Ohio State Alumni

A. F. Davis, Vice-President and Secretary of The Lincoln Electric Co. of Cleveland, Ohio, has been elected president, for a two-year term, of the Alumni Assn. of the Ohio State University. The association's 25,000 members are said to be the largest alumni organization among the Big Ten Conference schools. The Progress and Development Fund which the alumni sponsor is claimed to be the third largest in all the United States and is first in the number of contributors.

Davis graduated from Ohio State in 1913 with a degree in Electrical Engineering. He has been an ardent supporter of the University. He established and has developed there the A. F. Davis Welding Library which is the largest and most complete collection of material on welding any where in the world.

OBITUARY

George N. Sieger

George N. Sieger died suddenly April 1st at Indianapolis, Ind, while returning from a vacation in Florida.

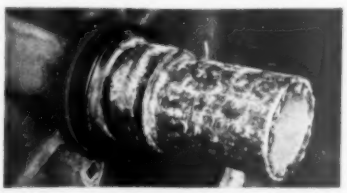
Mr. Sieger was a National Past-President of the AMERICAN WELDING SOCIETY, and the RWMA, Director of AMERICAN WELDING SOCIETY, Past-Chairman and Secretary of the Detroit Section.

Mr. Sieger attended Mercersburg Academy, then Lehigh University, where he graduated in Electro Metallurgy.

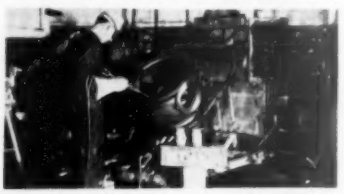
From 1912 to 1914 he was connected with the Continuous Zinc Smelting Co. as Metallurgical Engineer. From 1914 to

Build up with...
All-State No. 13
Nickel-Silver ☑
Retemper...
None
Required ☐

• Dirt Mover Gears and Pinions • Finely Heat Treated • Reclaimed in 14 hr. with 25 lb. All-State No. 13 • Saved $510. net.



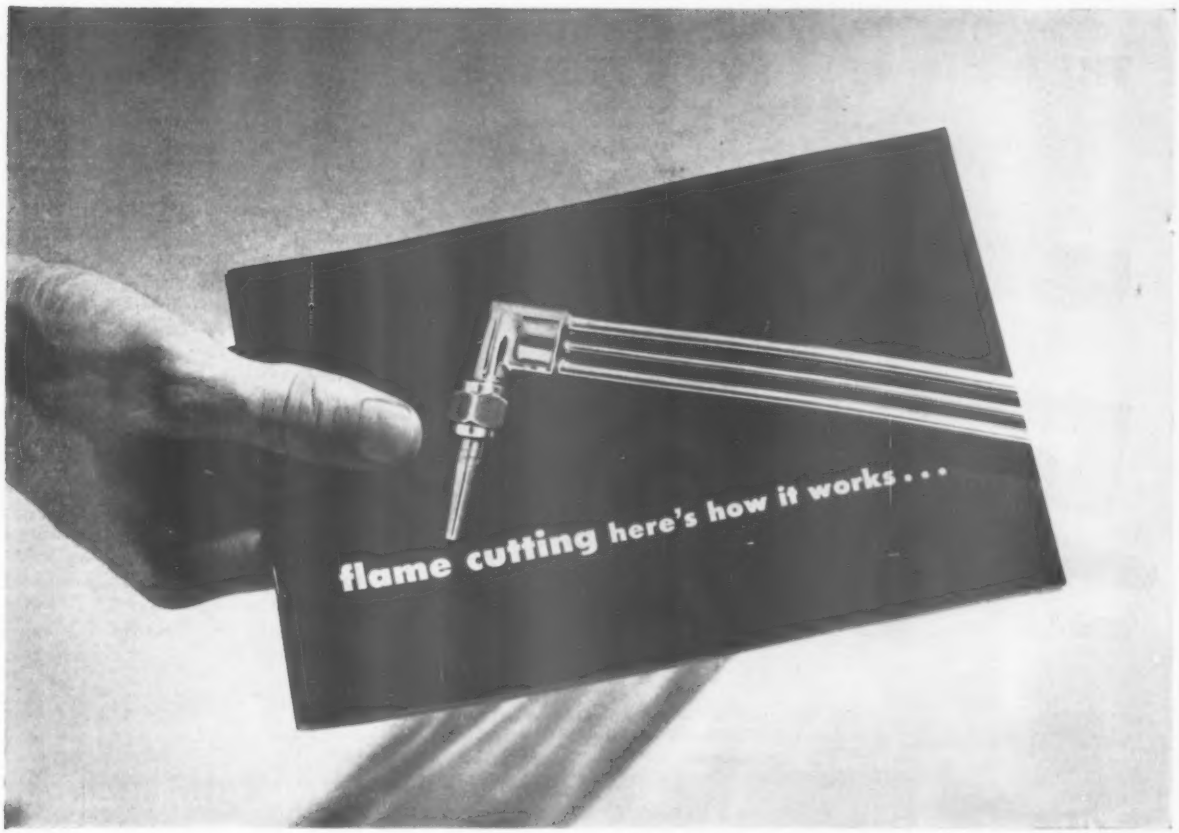
• Steam Processer Packing Gland Journal • None reclaimed before • 20 lb. of All-State No. 13 included in $300. overall repair • Saved replacement at $1300.



• Dripless Ball and Cone Valves • Rejections reduced to zero since adopting All-State No. 13 • High resistance to abrasion and galling is imperative.

All-State No. 13 Nickel-Silver Build-up Rod (and the No. 11 Brazaloy Flux that's always used with it) is sold just about everywhere. Over 600 All-State Distributors have it in stock. Write us for names of those near enough to you to be convenient. Ask for "Steel Booklet" to get complete application instructions.

All-State
ALL-STATE
WELDING ALLOYS CO., INC.
White Plains, N. Y.



this is a really good book, you will want a copy of it . . . free, while supply lasts

This forty page brochure is packed full of important, interesting and worth-while information; 27 fine photographs illustrate the well written text. Here are some of the subjects covered:

What is flame cutting . . . why preheating flames . . . one or many preheating flames . . . how important is the oxygen jet . . . how much oxygen pressure do we need . . . does pressure dictate volume . . . which fuel gas to select . . . and full details about how a cutting torch is designed and how it functions.

There are hints on how to select a cutting tip . . . and much added data of value to the experienced operator as well as for the rankest beginner. It's a good book and you will want to own a copy of it. Write today for YOUR FREE COPY.

NATIONAL WELDING EQUIPMENT CO.
218 Fremont Street, San Francisco 5, Calif.
Please send FREE "Flame Cutting" Booklet.

Name _____ Title _____

Company _____

Address _____

City _____ Zone ___ State _____

(Please print to make sure you receive your copy.)

528

Made by National WELDING EQUIPMENT CO., San Francisco 5, California

1915 he was associated with the Commercial Research Co. on Long Island. From 1915 to 1917 he was with the Davis Bournonville Co. as Welding Engineer, then was commissioned as a Lieutenant and went to France during World War I where he was promoted to Captain of Motor Transport and Company Commander.

After mustering out of the Army, Mr. Sieger went to Canada and from 1919 to 1924 he was Manager of the Canadian Consolidated Corp. in St. Catharines, Ont. From 1924 to 1933 he was Executive Officer of P. R. Mallory Co. and was instrumental in the formation of the Carboloy Co. and was its first employee.

In 1933 Mr. Sieger formed his own company, The S-M-S Corp., and during the second World War served on the War Production Board as a dollar-a-year man as consultant in the Cemented Carbide Tool Division.

Mr. Sieger was President and General Manager of S-M-S Corp. until his death. He leaves his widow, Mildred L., a daughter Betty Jane, and a son, Robert. He leaves one granddaughter, Patricia.

Employment Service Bulletin

Services Available

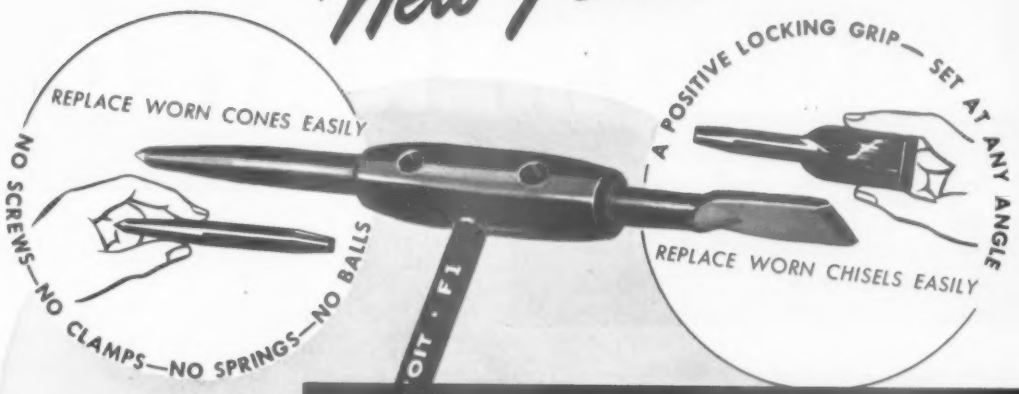
A-637. General Manager. Graduate engineer with 19 years' diversified experience in metal fabrication industry covering management, engineering and manufacturing. Seasoned in stampings, all phases of welding and mass assembly. Detailed in tooling engineering, labor relations, purchasing, sales and product engineering.

Positions Vacant

V-293. Flux Coating Technician—for setting up small plant to flux coat mild steel electrodes—must be thoroughly familiar with all practical details—please submit complete information in first letter.

V-294. Sales Representative—to contact welding supply distributors for established manufacturer of specialty line. Our business is expanding very rapidly and this is a chance to get in on the ground floor. We now have national distribution and this job involves working with established distributors as well as setting up new ones. Extensive traveling involved. Write including experience record and present earnings. Reply confidential.

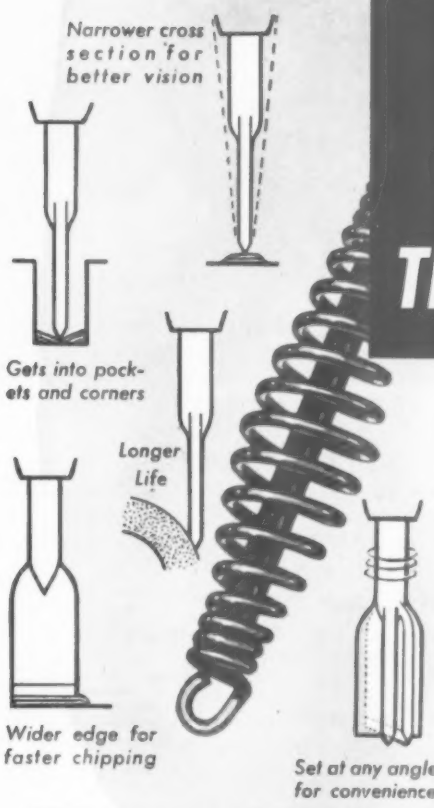
There's Never Been Anything Like It For *New Features!*


REPLACE WORN CONES EASILY
NO SCREWS—NO CLAMPS—NO SPRINGS—NO BALLS
A POSITIVE LOCKING GRIP—SET AT ANY ANGLE
REPLACE WORN CHISELS EASILY

"RE-BIT"

Economical! Practical!

The New ATLAS Tomahawk


Narrower cross section for better vision
Gets into pockets and corners
Longer Life
Wider edge for faster chipping
Set at any angle for convenience
Simple locking taper for fast replacement

THE BEST TOOL COSTS THE LEAST

—Because you use it over and over—Replace only the low cost bits—just as you replace only the tip in your cutting torch.

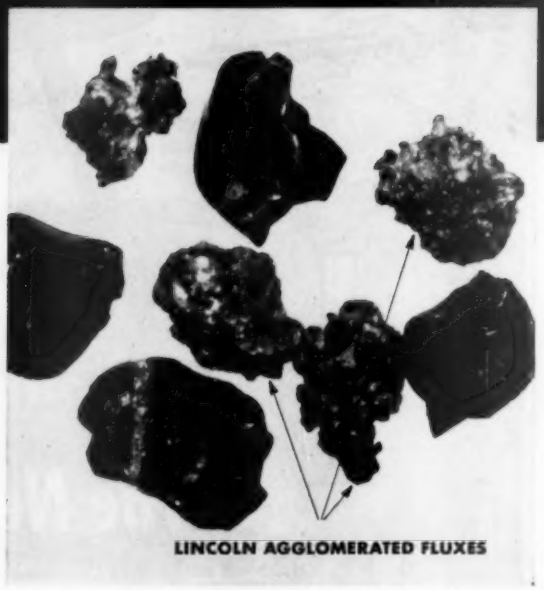
Model E 1 — Flexo handle — 12 ounces
Model F 1W — Flexo handle — 16 ounces
Model E 1W — wood handle — 12 ounces
Model F 1W — wood handle — 16 ounces

Chip the edges off your chipping tool cost —ask your local welding supply dealer to show you this Atlas tool!

Atlas WELDING ACCESSORIES CO.
707 E. LEWISTON AVENUE FERNDALE 20, (DETROIT) MICH.

Most widely used...for automatic welding...for automatic hardsurfacing

LINCOLN AGGLOMERATED FLUXES



Photomicrograph of Lincoln Fluxes—*Shows original ingredients held together in clusters with simple binder making each grain identical in composition.*

- ***COVER 30% MORE FOOTAGE***
- ***SAVE 45% ON COST***

AGGLOMERATED FLUXES... *another Lincoln first!*

Take another close look at the photomicrograph. It shows *why* you can cut costs of automatic welding through Lincoln's unique agglomerated flux.

Versatile—With Lincoln Agglomerated Fluxes, ingredients are held together in clusters with a simple binder. This means their original identity is retained ... available at the time of welding to affect the metallurgy of the weld. Alloys and deoxidizers can be introduced directly through the flux permitting virtually any type of deposit to be produced at low cost, using plain mild steel electrode. Note that *every grain is identical* in composition.

More Coverage at Less Cost

Density of Lincoln Agglomerated Fluxes is .69 of other fluxes, giving 30% more coverage. And these Agglomerated Fluxes sell at a lower price per pound ... directly saving 45% on cost.

for Automatic Welding

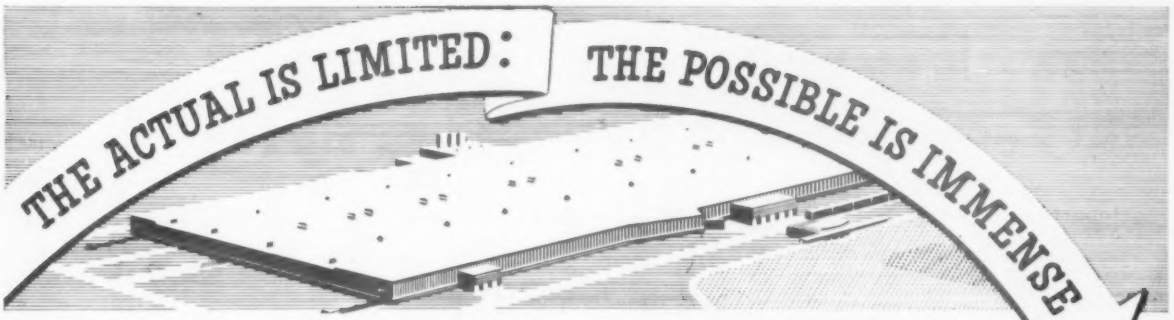
780 Flux for high speed, light gauge welding
760 Flux for single pass butt welds
840 Flux for fillets and multiple pass welds

for Automatic Hardsurfacing

H-545 Flux for Multiple Layer Deposits
H-550 Flux for Single Layer Deposits

GET THE FACTS. Specifications on Lincoln's Agglomerated Fluxes are in Bulletin 468. Available to welding and production engineers by writing on your letterhead to Dept. 1906.

THE LINCOLN ELECTRIC COMPANY
CLEVELAND 17, OHIO
THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

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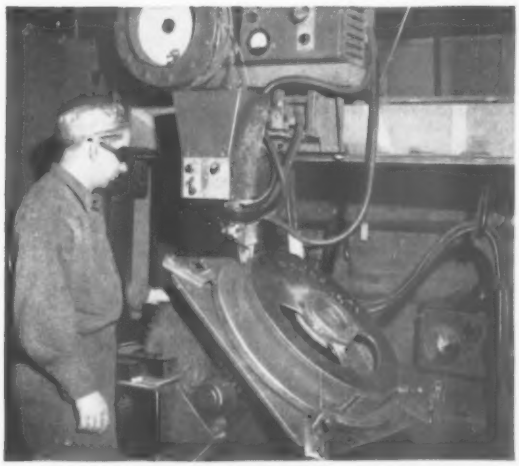
TO CUT WELDING COSTS: centralize welding responsibility with Lincoln's complete automatic service



Full Automatics—*"Automatic Lincolnweld" . . . industry's standard for fast, low cost quality "hidden-arc" welding. Available for mounting on fixtures or for tractor mounting on heavy flat work. "Twinarc" head may be quickly mounted to increase welding speeds 50% and more using two electrodes with same "Lincolnweld" controls.*

Semi-Automatics—*"Manual Lincolnweld," commonly known in industry as "squirt welder" . . . leader in high-current density welding. Combines fast, low cost benefits of automatic welding with flexibility of hand welding. Easy to set up . . . the "Manual Lincolnweld" gun may be mounted in simple, low cost fixtures for flat and near flat work.*

Unique Agglomerated Fluxes—Cover 30% more footage at 45% less cost. In Lincoln Agglomerated Fluxes ingredients are held together with a simple binder . . . to retain *original identity* at the time of welding. The ingredients are not lost or changed in composition. *Every grain is identical!* Furthermore, alloys can be added to produce any type of weld deposit with mild steel wire. Fluxes 760, 780 and 840 are for automatic welding. Flux H-545 is for hardsurfacing for severe impact. Flux H-550 is for severe abrasion.

Automatic Electrodes—For mild steel

- L-60 . . . mild steel wire .12 carbon
- L-61 . . . mild steel wire .12 carbon silicon killed
- L-70 . . . alloy steel wire .14 carbon plus .5% moly.
- L-201 . . . medium carbon steel wire (.55 carbon)
- L-18/8 . . . stainless steel wire

"Automatic" Engineering—Benefit from Lincoln's complete application engineering service available throughout the country. Automatic welding specialists, located in every principal industrial area, will gladly analyze your welding needs, suggest the most efficient tooling and welding procedures for lowest cost operation. Call or write

THE LINCOLN ELECTRIC COMPANY

DEPT. 1906, CLEVELAND 17, OHIO

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

NEW LITERATURE

Hobart Arc Welding News

Volume X. No. 1 and 2, *Hobart Arc Welding News*, a 16-page and 20-page booklet respectively of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in arc welding.

Many of the articles feature time and money saving applications. To get your copies, write the Hobart Brothers Co., Troy, Ohio.

Success Through Welding

A 50-page booklet presenting the stories of 25 men who have achieved success with their small businesses; each is a story of how an individual with an idea has, through his own ability and hard work, built a successful business. The stories all have in common the one fact that the arc welding process has been the foundation of the business described. Companies are making such things as swings, snow plows, water tanks and grandstands. Price 50 cents in U.S.A., 75 cents elsewhere. Publisher, The Lincoln Electric Co., Cleveland 17, Ohio.

Silver Brazing Preforms

A technical bulletin on *Silver Brazing Preforms* has recently been produced for the brazing industry by the Lucas-Milhaupt Engineering Co. of Cudahy, Wis. A copy of this 10-page booklet may be obtained by writing directly to the company.

British Engine Technical Report, New Series—Volume I

The British Engine Boiler & Electrical Insurance Co. Ltd. of Manchester, England, has recently issued a new publication entitled *Technical Report, New Series—Volume I*. This 212-page book reflects some of the experiences acquired by the company in the course of its work, which includes periodical inspection, testing and certification of power plant and kindred machinery. Among the 30 cases covered in this publication are "Butt-Welded Joints in Pipe Ranges" and "Failure of Rotating Shafts Due to Repairs by Welding."

Technical Report, New Series—Volume I is being distributed to interested persons in the USA by the Royal-Liverpool Insurance Group, 150 William St., New York 38, N. Y.

1952 Book of ASTM Standards Issued

With over 9975 pages, including the more than 2001 standards, specifications, tests and definitions for materials, the *1952 Book of ASTM Standards* is issued in Seven Parts.

This book, used not only in the United States and Canada but throughout the world for purchases of materials, and particularly for evaluating their quality through the standard tests that are given, is made up as follows:

Part		Standards	Pages
1	Ferrous metals	291	1602
2	Nonferrous metals	268	1359
3	Cement, concrete, ceramics, thermal insulation, road materials, waterproofing and soils	405	1666
4	Paint, naval stores, wood, fire tests, sandwich constructions, building constructions	273	1182
5	Fuels, petroleum, aromatic hydrocarbons and engine Antifreezes	213	1282
6	Rubber, plastics and electrical insulation	257	1520
7	Textiles, soap, water paper, adhesives and shipping containers	294	1364

Each part of the 1952 book is complete with detailed subject index, two tables of contents arranged to provide the thousands of technologists and others in industry and government with as usable a book as possible.

Copies may be obtained from The American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Clamp Catalog

The Adjustable Clamp Co. of Chicago announces the publication of their new *Catalog No. 18*, which is now available for general distribution. This 28-page edition describes the complete "Jorgensen" and "Pony" line of clamps and handscrews, including the shielded welders' clamps.

The catalog is unusually well illustrated and descriptive, and includes, in addition to ordinary "catalog details," many how-to-do-it suggestions.

Copies of the new catalog are available upon request to Adjustable Clamp Co., 417 N. Ashland Ave., Chicago 22, Ill.

Sciaky Bulletin

Sciaky Bros., 4915 W. 67th St., Chicago, Ill., *Bulletin No. 309-10* covers the Sciaky Locating Spotlight which enables production machine operators to accurately position work in blind operations on all types of equipment.

The Sciaky Locating Spotlight reportedly eliminates the necessity of expensive fixtures and guides in many cases. The machine operator can position work without the help of an extra man. Quick and easy to use, the Sciaky Locating Spotlight can increase production on the most difficult blind operations, according to the manufacturers.

The Sciaky Locating Spotlight directs an intense pin-point beam of light on the stationary member of the machine. Thus, whether the assembly is marked or drilled, the operator is always sure of accurately positioning the piece part. It is claimed that while the light is clearly visible under all shop conditions on all materials, its brightness will not cause eyestrain.

A-C Welding Equipment Booklet

Three basic alternating-current welding machines and their accessories are appraised in a 17-page booklet available from the Westinghouse Electric Corp.

Pointing to the great variety of a-c welding applications, this booklet shows how (1) a general purpose unit, (2) a 200-amp welder with a built-in high-frequency stabilizer and (3) a general and special purpose 80-v machine provide the answers to practically any a-c welding problem. It also shows that when a-c welders are substituted for d-c welders, savings are realized in production time, power maintenance and depreciation. Charts and formulas for figuring these potential savings are given.

Each basic type of welder is described from the standpoints of construction, operation and application. Electrical specifications, physical dimensions and weights of the various models are given, and special characteristics such as built-in power factor correction are described in detail. Optional equipment and standard accessories include running gear, remote control attachments, high-frequency arc stabilizers, and the usual helmets, electrode holders and ground clamps.

For a copy of this booklet, B-5622, write the Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

Low Temperature EUTECTIC WELDING ALLOYS

stops mild steel welding failures

minimize stress ...distortion ...warpage with Low Temperature EUTECTIC WELDING ALLOYS

impossible?...that's what the Stolper Steel Products Corporation thought, too, until they actually tried these **new,** entirely different EUTECTIC "Low Amp"® EutecTrodes.® Then they came up with the astounding Case History shown below... Yes, we not only **claim** this amazing performance...we **prove** that "Eutectic" is different... prove that these new alloys **solve** metal-joining problems **where conventional materials fail!**... Let us prove it in your shop... just as we have in over **78,000** other plants and shops throughout America... There's no cost, no obligation involved... just fill in and **mail** the coupon below for a **free** consultation-demonstration from one of our 350 trained District Engineers who stand ready to serve you from coast to coast.

AMERICA'S LEADING INSTITUTION
DEVOTED TO THE RESEARCH AND MANUFACTURE OF
SPECIALIZED METAL-JOINING ALLOYS

Not only "MILD" steel, but also high carbon steel; cast steel; high-speed steel; manganese steel; stainless and all alloy steels; structural steel; aircraft steel, etc., in addition to all other metals from "A" for Aluminum to "Z" for Zinc can be joined faster, better, and more economically with one of the more than 150 different "Eutectic Low Temperature Welding Alloys".(All arc, torch and furnace applications.)

FREE...
72 PAGE BOOK! "Manual of Welding Design and Engineering" with 50 new photos, 60 new drawings. Send for YOUR free copy TODAY

SAVES 40% ON LEAD-COATED STEEL-PLATE WELDING COSTS

"Having just completed a series of tests using EUTECTIC's rods on Terne Plate tanks, I thought you would be interested in the following typical results.

TIME SAVINGS PER 100 TANKS!

Airtack and weld complete...43.7%
Wire Brush welds.....18.6%
Test and Repair leaks.....32.6%

"This reflects a savings of 43.85 hours (40%) per 100 tanks. The comparisons were made on production runs and the hours per 100 tanks shown are actual time study standards used for incentive purposes.

"I wish to thank you for the splendid cooperation which made this savings possible." —*L. L. D., Ind. Eng., Stolper Steel Products Corp.*

EUTECTIC WELDING ALLOYS CORPORATION
172nd Street & Northern Boulevard, Flushing 58, New York, N. Y.
WJ-6

This new manual of yours sounds like a very helpful book. Send me a FREE copy with the understanding that there will be no cost or obligation now or later.

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Firm .....
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City..... State.....

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Weld it once and done

no cracks, no porosity

Lightweight, tough, high tensile steels have made it possible for truckers to haul heavier loads with less dead weight—a decided economy.

No less important in saving time and money is the use of low hydrogen electrodes to weld these steels. When you weld low alloy high tensile steels—whether your requirements are tough or easy—Arcos Low Hydrogen Electrodes will consistently produce sound welds . . . welds that are free of cracks or porosity. There is no reworking of such welds—no chipping or re-welding to add more time to the job. The ability of Arcos weld metal to stand up in tough service—such as the strain on truck bodies of heavy loads or the impact of sudden stops and starts—is the result of high standard quality controls in the manufacture of Arcos electrodes.

Send for the free Arcos booklet, "The ABC's of Welding High Tensile Steels". Arcos Corp., 1500 South 50th Street, Philadelphia 43, Penna.

ARCOS GRADE	A. W. S. SPEC.
Tensilend 70	E7016
Tensilend 100	E10016
Tensilend 120	E12015
Manganend 1M	E9015
Manganend 2M	E10015
Nickend 2	E8015
Chromend 1M	E8015
Chromend 2M	E9015

See us at the Houston Show
Booth 63 and 64.

WELD WITH ARCOS

LOW HYDROGEN ELECTRODES

A. O. Smith Brochure

A new brochure, *The Spotlight Is on A. O. Smith*, issued by the Welding Products Division of A. D. Smith Corp., Milwaukee 1, Wis., gives fullest specifications on all available machines and tells the customer of the many types of welding electrodes and welding accessories sold by the division.

Kaiser Aluminum News

Sidewalk engineers are still talking about the 120-ft high aluminum tower constructed by the Girdler Corp. of Kentucky. Reason: The tower was erected "from the top down" instead of "from the bottom up." One secret of Girdler's success in building the tower was the sigma welding process developed by the Linde Air Products Co. of New York, according to a feature in the April issue of *Kaiser Aluminum News*.

Published by Kaiser Aluminum & Chemical Corp. *Kaiser Aluminum News* is read by approximately 20,000 users of light metals from coast to coast. Copies may be obtained by writing to Kaiser Aluminum & Chemical Corp., Kaiser Building, Oakland, Calif.

New Catalog of Isotopes

A new catalog of isotopes, both radioactive and stable, produced by Oak Ridge National Laboratory, Oak Ridge, Tenn. is now available, according to an announcement by the Laboratory. The catalog replaces a previous edition published by the Atomic Energy Commission in March 1951.

Oak Ridge National Laboratory, which is operated for the AEC by Union Carbide and Carbon Corp., is not only the largest laboratory of its type in this country but is the foremost producer and distributor of radioisotopes and stable isotopes for use in medicine, agriculture, industry and science.

More than 100 radioactive and 175 stable isotopes are listed in the new catalog, together with prices and descriptive material. Prices range from as low as $5.00 per curie for radioactive cobalt (in large quantities) to $5.00 a microcurie for radioactive chlorine.

The catalog—at $1.00 per copy—or information about ORNL-produced radioisotopes, may be obtained by writing to Carbide and Carbon Chemicals Co., Oak Ridge National Laboratory, Radioisotope Sales Department, P. O. Box P, Oak Ridge, Tenn. Correspondence regarding stable isotopes should be directed to Carbide and Carbon Chemicals Co., Oak Ridge National Laboratory, Stable Isotope Research and Production Division, P. O. Box P, Oak Ridge, Tenn.

Metal-Cutting Guides

A new bulletin, No. 101, describing and illustrating their complete line of NEECO Guides for hand-held cutting torches has been published by New Era Engineering Co., Chicago, Ill.

Recently introduced to industry, the new NEECO Guides have been designed to give the workman greater accuracy than ever before possible with hand-cutting torches. Attached to torches quickly without tools, the guides provide a means for fast, accurate cutting of circles, straight lines, angles, bevels and sundry shapes.

NEECO Guides are made in styles to fit all makes of torches (from 70- to 90-deg models). They are of three principal types: a small circle guide for cutting circles 1 to 15 in. in diameter, a large circle guide for cutting circles 10 to 66 in. in diameter and a straight-line guide. The new *Bulletin 101* describes and illustrates each of these various styles, with prices and shipping weights included in the guide descriptions.

Copies of the new bulletin can be had by writing to the manufacturer, New Era Engineering Co., Dept. B95, 458 W. 29th St., Chicago 16, Ill.

Heliarc Torch Catalog

Details and specifications of the newest Heliarc torches have been combined by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., in their recently released catalog, *Heliarc Torches: Your Best Buy for Inert Gas Shielded Arc Welding* (Form 7979). All Heliarc torches described in this new booklet have the latest developments in the inert-gas-shielded arc-welding field, such as maximum inert-gas-shielding coverage, all-inclosed cooling water passages, water-cooled power cables, easily maintained parts and quick-release electrode collets.

In addition, this catalog contains charts giving selection data on electrodes, nozzles and argon cylinders along with detailed information on argon regulators and flow meters.

The catalog may be obtained free of charge from your local Linde representative or by writing directly to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Hard-Facing Alloy

Information on applying Colmonoy No. 6, a versatile, all-purpose hard-facing alloy that may be applied by oxy-acetylene or electric arc welding, hot formed as an overlay, applied in the form of castings, or sprayed on, is now available in a pamphlet (No. 104) by Wall Colmonoy Corp. 19345 John R Street, Detroit 3, Mich.

When you want
to **lick corrosion**
for longer equipment life

Getting good corrosion resistance starts with a base metal of desirable characteristics. However, maximum equipment life can be assured only when the welds possess the same corrosion resistance as the base metal.

ARCOS STAINLESS ELECTRODES are designed to deliver the results you need on *all* your welding jobs. Regardless of the requirements, there's a wide selection to provide the best suited electrode for every application. Because each is backed by Arcos quality controls, you have complete assurance of physically, chemically, and metallurgically sound weld metal. That means longer-lasting welds . . . less time and fewer dollars for maintenance. Write for your free copy of "What Electrode Would You Use?"

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Philadelphia 43, Pennsylvania

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ARCOS
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ZIRTUNG DISPLAYS...

THEY TELL ABOUT A REAL MONEY SAVER!

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The amazing new electrode that far outlasts ordinary tungsten electrodes, minimizes contamination, reduces electrode consumption
EXCLUSIVELY DEVELOPED BY SYLVANIA FOR INERT GAS ARC WELDING
ZIRTUNG
SYLVANIA

Keep on the lookout for these dramatic, colorful store and window displays. They tell you where you can get ZIRTUNG Electrodes . . . Sylvania's new, exclusive development for inert gas arc welding. Start using Zirtung today and find out why more and more welders say: "Zirtung saves time, saves material, saves money!"

Compare Longer-Lasting ZIRTUNG With the Rod You're Using

This new tungsten-zirconium alloy self cleans contamination without loss of electrode. Lasts far longer than ordinary rods and assures sound dependable welds every time.

Zirtung operates on the same current range as thoriated tungsten. Contains no radio-active material. Wonderful for welding stainless and mild steels, aluminum, and magnesium. For further details, call your nearest Sylvania Welding Distributor or write to: Sylvania Electric Products Inc., Dept. 3T-4906, 1740 Broadway, New York 19, N. Y.

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ARIZONA

PHOENIX: Adroit Mfg. & Supply Co.; Arizona Welding Equipment Co.

ARKANSAS

LITTLE ROCK: Welders Supply Co.

CALIFORNIA

FRESNO: Baker's Welding Supply Co.; **GLENDALE:** H. M. Parker & Son; **LONG BEACH:** H. I. Tullis Welding Supplies; **LOS ANGELES:** Absco Welding Supplies; Anderson Equipment Co.; Pacific Welding Alloys Man. Co.; Victor Equipment Co.; H. C. Witherspoon Co.; **ONTARIO:** A & R Equipment; **SACRAMENTO:** Moore's Welding Supply Co.; **SAN BERNARDINO:** Ted Cox Welding Supplies; **SAN DIEGO:** Bailey Equipment Co.; **SAN FRANCISCO:** Victor Equipment Co.; Welding Service Sales, Inc.; **SAN JOSE:** Arnold Bros. & Herrero

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FLORIDA

MIAMI: Miami Welding Supply, Inc.; **TAMPA:** General Auto Supply Co., Inc.

GEORGIA

ATLANTA: Welding Supply & Service Co.; Lee S. Wolfe & Co.; **AUGUSTA:** Marks Oxygen Co.

ILLINOIS

CHICAGO: Alloy Welding Sales Corp.; Benster Welding Supply Co.; Brock-Smith Welding Sales; Chicago Welding Sales Co.; Eagle Welding Equipment Co.; Harris Welding Equipment Co.; Johnson Welding Equipment Co., Inc.; Machinery & Welder Corp.; Peterson Welding Supply Co.; F. G. Squire Co.; Triangle Machine Works, Inc.; Universal Welding Supply Co.; **DANVILLE:** Depke Service; **ROCKFORD:** Welders Supply Co.

INDIANA

EAST CHICAGO: Metal & Thermit Corp.; **ELKHART:** Auto Specialties Co., Inc.; **FT. WAYNE:** Wayne Welding Supply Co., Inc.; Sutton-Garten Co.; **INDIANAPOLIS:** Allied Weldcraft, Inc.; Indianapolis Welding Supply Co.; Welding Equipment & Supply Co.; **MISHAWAKA:** C. A. Schrader Welding Supply; **SOUTH BEND:** Mittler Supply, Inc.; **TERRE HAUTE:** Hobart Dist. Co.

IOWA

CEDAR RAPIDS: The Kacena Co.; **DAVENPORT:** Jacobs Welding Supply; **WATERLOO:** Newkirk Sales & Service

KANSAS

WICHITA: Lampton Welding Supply Co.

KENTUCKY

PADUCAH: Hannan Supply Co., Inc.

LOUISIANA

NEW ORLEANS: Gulf Welding Equipment Co.

MAINE

AUBURN: Maine Oxy-Acetylene Supply Co.

MARYLAND

BALTIMORE: Delta Oxygen Co.; Earlbeck & Landrum, Inc.; Guilford Welding Supply Co.; Prest-O-Baltimore Co., Inc.; The Welders' Supply Co.; **HYATTSVILLE:** District Oxygen Co., Inc.

MASSACHUSETTS

BOSTON: Arthur C. Harvey Co.; **CAMBRIDGE:** Welders Supply Co., Inc.; **COHASSET:** D. S. Kennedy & Co.; **EVERETT:** Middlesex Welding Supply Co.; **MALDEN:** Welding Service Co.; **SPRINGFIELD:** Jaeger Welding Supply, Inc.; **WEST SPRINGFIELD:** Crescent Welders Supply Co.

MICHIGAN

DETROIT: Bird Gas Corp.; J. L. Oswald Co.; Robinson Welding Supply Co.; Welding Equipment & Supply Co.; Welding Gas & Equipment Co.; Welding Metals Mfg. Co.; **FLINT:** Genesee Welding Supply, Inc.; Gransden-Hall & Co.; **GRAND RAPIDS:** Purity Cylinder Gases, Inc.; Welding Gas & Supply Co.; **JACKSON:** Michigan Welding Supply Co.; **LANSING:** Michigan Welding Supply Co.; **SAGINAW:** Saginaw Welding Supply Co.

MINNESOTA

ROCHESTER: Gopher Welding Supply Co.; **ST. PAUL:** Production Materials Co.

MISSOURI

KANSAS CITY: Kirk-Wiklund & Co.; Welding Equipment Supply Co., Inc.

NEBRASKA

OMAHA: Balbach Co.

NEW HAMPSHIRE

MANCHESTER: New Hampshire Welding Supply Co.

NEW JERSEY

ELIZABETH: Interstate Welding Supply Co.; **JERSEY CITY:** Garden State Welding Supply Co.; **LINDEN:** J. W. Goodliffe & Son; **NEWARK:** Essex Welding Equip. Co., Inc.; Hobart Welding Equipment Co.; Charles W. Krieg Co.; Welding Service Co.; **NORTH BERGEN:** Auto Gas Light & Appliance Co., Inc.; **PLAINFIELD:** Jersey Welding Supply, Inc.; Thermionic Products Co., Inc.; **TRENTON:** Mercer Oxygen & Supply Co.; **UNION CITY:** The Alton Co.

NEW YORK

ALBANY: Albany Calcium Light Co.; Albany Welding Supply Co.; **BINGHAMTON:** Welders Supply Co.; **BRONX:** Arc Welding Supply Co.; **BROOKLYN:** Acetylene & Welding Equipment Co.; Bitumen Welding Supply Co.; Kaplan Brothers; **BUFFALO:** Buffalo Welding Supply Co.; Hobart Welder Sales & Service; Mills Welding Supply, Inc.; Rodgers Welding Supply Co.; **JAMESTOWN:** Weldery Supply Co.; **LONG ISLAND CITY:** Eastern Welding Equipment Co.; The K-G Equipment Co., Inc.; Prest-O-Sales & Service, Inc.; Special Welding Alloy Co., Inc.; **MINEOLA:** General Welding Supply Corp.; **NEWBURGH:** Peterkin Welding Supply Co.; **NEW ROCHELLE:** County Welding Products Inc.; **NEW YORK:** Harold Dessau, Inc.; Independent Welding Supply Co.; McKinney Welding Supply Co.; New York Welding Supply Co., Inc.; T. W. Smith Welding Supply Co.; Whitehead Metal Products, Inc.; **NIAGARA FALLS:** Falls Welding Supply Co.; **ROCHESTER:** Jackson Welding Supply Co.; Welding Supply Corp.; **SYRACUSE:** Cottet's Welding Supply Co.; Welding Engineering & Equipment Co.

NORTH CAROLINA

CHARLOTTE: National Welders Supply Co., Inc.

OHIO

AKRON: Akron Welding & Spring Co.; **CANTON:** Welders Supply Co.; **CINCINNATI:** Atlas Company; Miller Equipment Co.; O. K. I. Welding Supply Co.; X-L Supply Co.; **CLEVELAND:** Burdett Oxygen Co. of Cleveland, Inc.; **COLUMBUS:** Chrismer-Hull Co.; **MARTINS FERRY:** James C. Dawes Co.; **TOLEDO:** Welder Service Co.; Welders Needs, Inc.; **TROY:** The Hobart Brothers Co.; **YOUNGSTOWN:** Welder's Sales & Service

OKLAHOMA

OKLAHOMA CITY: Kraut Welding Supply Co.; Mideke Supply Co.

OREGON

PORTLAND: Industrial Specialties Co.

PENNSYLVANIA

ERIE: Boyd Welding Co.; Welders Supply Co.; **NORRISTOWN:** E. R. Joseph; **PHILADELPHIA:** Arcway Equipment Co.; J. A. Cunningham Equipment, Inc.; Gas Arc Supply; R. S. McCracken & Son, Inc.; **PITTSBURGH:** Allegheny Welding Supply Co.; Metal & Thermit Corp.; Weber-Semmer Co.; Weldcraft Equipment Co.; Williams & Co.; **PROSPECT PARK:** Urie & Blanton; **READING:** Grauert & Co.; F. Jones Welding Co.; **SCRANTON:** Mitchell Welding Supply; Scranton Welding Supply Co.; **WILLIAMSPORT:** Porter Welding Co.

RHODE ISLAND

PROVIDENCE: Corp Brothers

SOUTH CAROLINA

GREENVILLE: Fortson Welding Supply Co.

TENNESSEE

CHATTANOOGA: Brooks Welding Supply Co.; C. G. Genter Co.; **MEMPHIS:** Beaver Welding Supply Co.; Delta Oxygen Co., Inc.; Standard Welders Supply Co.

TEXAS

DALLAS: Briggs Weaver Machinery Co.; Texas Welding Supply Co.; Welders Supply, Inc.; **FORT WORTH:** Industrial Welding Supply Co.; **HOUSTON:** Acme Welding Supply, Inc.; **VICTORIA:** Welders Equipment Co.

VIRGINIA

RICHMOND: Welders Supply Co. of Richmond; **ROANOKE:** Jones Welding Supplies

WASHINGTON

SPOKANE: Gibson Welding Supplies; Spokane Welder Supply Co.; Spokane Oxygen Service; **TACOMA:** Oxygen Sales & Service Co.

WEST VIRGINIA

CHARLESTON: Virginia Welding Co.

WISCONSIN

KENOSHA: H. R. Kelsey Welding & Engineering Co.; **MADISON:** Badger Welding Supplies; Richard E. Ela Co.; Red Arrow Sales Corp.; **MILWAUKEE:** Acme Welding Supply, Inc.; Bentley Sales Co.; Norton Welding Equipment Co.; Viking Welding Supply Co.; **RACINE:** Bentley Welding Supplies Inc.; Machinery & Factory Equip. Co.; **SHEBOYGAN:** Van Havaren Welding Supply Co.; **WAUSAU:** Northern Auto Supply; **WAUKESHA:** Bradshaw Welders Supply; **WISCONSIN RAPIDS:** Rapids Welders Supply Co.

HAWAII

HONOLULU: Hawaiian Gas Products, Ltd.

CANADA

MONTREAL: L'Air Liquide Society; Welding & Supplies Co., Ltd.; **TORONTO:** British Oxygen Canada Ltd.

PUERTO RICO

SAN JUAN: Portilla Corp.

NEWS OF THE INDUSTRY

Prices on Inert-Gas-Arc Welding Wires

Air Reduction recently announced new low prices on spooled wires for Aircomatic, Heliwelding and other inert-gas-arc welding processes. Materials include aluminum, stainless steels and copper-base alloys.

Data sheets on stainless steels and price lists on all items may be obtained by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

New A. O. Smith Distributors

Welding Products Division of the A. O. Smith Corp., Milwaukee 1, Wis., announces the addition of three new distributors of welding electrodes, welding machines and welding accessories. They are: Pensacola Welding Supply Co., Inc., 507 Palfox, Pensacola, Fla; Worland Oxygen Co., P. O. Box 730, Worland, Wyo.; and Guilford Welding Supply Co., 1600 Guilford Ave., Baltimore 2, Md.

GE Simplifies Welding Electrodes Nomenclature

A new method of classifying and coding General Electric welding electrodes according to the universally accepted nomenclature of the AMERICAN WELDING SOCIETY has been announced by the company's Welding Department.

The new GE system, according to company engineers, will facilitate the right selection of an electrode for any job, permit proper storage conditions for electrodes to be easily determined, and enable new men to be trained quickly in the selection of correct electrodes.

The nomenclature change is planned basically to use numbers which can be immediately associated with AWS numbers. For example, AWS E-6011 can be analyzed as follows: First two digits (60) mean 60,000 psi minimum tensile strength. Third digit (1) means an all-position electrode. Fourth digit (1) means a-c d-c deep penetration, high-quality weld.

The G-E W-26 which is an AWS E-6011 electrode, will now be called W-611A. The second digit (0) has been omitted, so the 6 stands for 60,000 psi per tensile. The "A" has been added to facilitate ordering when GE has more than one electrode in a particular class.

No change will be made in the General Electric stainless steel, hard-surfacing, cast iron and other special types of electrodes.

Steel Plate Size Selector

An improved steel plate size selector has been made available by Lukens Steel Co., Coatesville, Pa., for the convenience of designers, engineers and others interested in steel fabrication.

The size selector is a durably made plastic slide rule that determines the longest and widest steel plates obtainable in any desired thickness from Lukens facilities. These sizes range from 24 to 195 in. in width, or from $^3/_{16}$ to 25 in. in thickness.

The reverse side of the selector permits the calculation of weights of rectangular and circular steel plates. A table of decimal equivalents and weights is also included.

Alloy Rods Co. Adds Six Distributors

Six welding supply companies have joined the expanding national distributor organization of the Alloy Rods Co., York, Pa., leading manufacturer of alloy arc-welding electrodes, according to an announcement by E. R. Walsh III, general sales manager.

The new distributors for Alloy Rods Co. arc-welding electrodes are: Charles Day Machine Shop, Brownwood, Tex.; Franklin Supply Co., Columbus, Ohio; G. L. Meerian Co., 54 School St., Greenfield, Mass.; Auto Battery & Electric Co., New London, Conn.; County Welding Products Corp., New Rochelle, N. Y.; Bob & Bill Welding Service, Plainview, Tex.

GE Welding Distributor

Consolidated Welding Supplies, Inc., 1939 Tulane Ave., New Orleans, La., has been named GE welding distributor for the New Orleans-Baton Rouge area, according to an announcement by the General Electric Co.'s Welding Department.

The company, which will handle the complete line of GE welders, electrodes and accessories, is managed by two AMERICAN WELDING SOCIETY members, C. A. Young, Jr., and W. G. Blackwell.

Mr. Young has had 17 years of experience as a welding specialist, much of it as a General Electric welding sales engineer in the Southeast. Mr. Blackwell, well known through the trade magazines for his articles on welding, served with General Electric as electrode field engineer and has worked on application methods for all phases of the welding industry.

Murex Electrodes

Metal & Thermit Corp. announces that its Murex line of stainless-steel arc-welding electrodes is now being packed in hermetically sealed metal cans. The smaller diameters come in 5-lb containers and the larger diameters in 10-lb containers.

Packing in airtight containers eliminates any possibility of moisture pickup by the electrode coatings from the time the electrodes are made until cans are opened for use and, it is claimed, assures consistent peak performance. In addition storage problems are simplified and shipping damage is held to a minimum.

The Murex line of stainless-steel electrodes includes lime-coated, titania-coated and a-c, d-c rods in all standard analyses as well as in a wide variety of the less commonly used grades.

Complete data on the line may be had by writing to Metal & Thermit Corp., 100 E. 42nd St., New York 17, N. Y.

Weldwire Triples Plant Space

The Weldwire Co., Inc., located at the NW corner of Emerald and Hagert Sts. in Philadelphia, Pa., begins its third year in the welding field.

This company has pioneered in chemically processed and precision layer-level spooled aluminum wire for the inert-gas-shielded arc-welding processes. Steel, low alloy, stainless steel and nonferrous alloys are being processed in the same manner.

In the domain of coated arc-welding electrodes, the Weldwire Co. has developed and put on the market a low-hydrogen lime-type low-alloy a-c, d-c electrode with a wide range of analysis.

Three types of coated stainless steel electrodes are being marketed: (1) lime d c; (2) titania a c, d c; and (3) lime a c, d c.

A new and varied line of nonferrous coated arc-welding electrodes has been developed, including excellent phosphor bronze, silicon bronze, aluminum, nickel, cupro-nickel and Monel electrodes.

A mild steel electrode with very deep penetrating characteristics, which can be used without edge preparation of plates up to $^3/_4$ in. thick, has been developed.

According to reports of the Weldwire Co., the organization has effected three distinct expansions and has tripled plant space since placing its developments into production in March 1952.

Weldwire Appoints Theger Co. as Southwestern Distributor

Theger Co., Houston, Tex., now serves as the distributor of the welding products of Weldwire Co., Inc., Philadelphia, Pa. Specialty coated arc-welding electrodes, spooled and coiled wires for automatic welding and arc-cutting equipment by Weldwire round out a varied line of welding fabricators supplies.

Dr. Wm. G. Theisinger founded Theger Co. to sell and service the technical products required by fabricators of alloy products. The new company, with offices at 2518 Drexel Drive, Houston 19, will handle Weldwire products and services in Texas, Louisiana, Oklahoma, Arkansas, Mississippi and western Tennessee.

Dr. Theisinger was born in Carlisle, Pa., in April 1904. After attending Harrisburg, Pa., public schools, he became assistant chemist at the Harrisburg Steel Corp. In 1925 he became associated with the Board of Transportation of the City of New York and worked on the development of welding inspection methods. In 1930, Dr. Theisinger matriculated at Harvard University, receiving the degree of Bachelor of Science in 1934. That summer he served the Western Pipe and Steel Co. at San Francisco as consulting engineer on high amperage, automatic welding. In 1935, after completion of postgraduate work at Harvard, he received the degree of Doctor of Science (Metallurgy).

Dr. Theisinger joined Lukens in 1935 as welding and metallurgical engineer and specialized in the handling of technical matters involved in the application, fabrication and sale of the company's products. He advanced through various executive positions until his promotion to manager of quality steel sales and then to regional manager of sales in June 1950 with offices in Houston, Tex., covering the territory from Georgia to California and north as far as Kansas City, Mo. During 1952, he served six months as Chief of the Plate Section, Iron and Steel Division, National Production Authority, Washington, D.C.

Dr. Theisinger holds memberships in the AMERICAN WELDING SOCIETY and the American Institute of Mining and Metallurgical Engineers. He received the Sauveur Memorial Award for 1951.

ASTM 56th Annual Meeting

The 1953 Annual Meeting of the American Society for Testing Materials will have Symposiums on Metallic Materials at Low Temperatures, Fluorescent X-ray Spectrographic Analysis, Radioactivity in ASTM Work, and Techniques for Electron Metallography.

Eight technical symposiums and many other technical papers on a wide range of subjects in the field of engineering materials are on the program of the 56th Annual Meeting of the American Society for Testing Materials at Chalfonte-Haddon Hall, Atlantic City, N. J., June 28th to July 3rd, inclusive.

Jerome Strauss, Vice-President, Vanadium Corporation of America, will present the second H. W. Gillett Memorial Lecture (Tuesday afternoon, June 30th) on the subject "Micrometallurgy."

Some of the papers to be presented at the Symposium on Metallic Materials at Low Temperatures (sponsored by the Joint Committee on Effect of Temperature on the Properties of Metals) are:

"Brittle Failure in Ships and Other Steel Structures," K. K. Cowart, U. S. Coast Guard.

Analysis of Brittle Behavior in Ship Plates," M. L. Williams, National Bureau of Standards.

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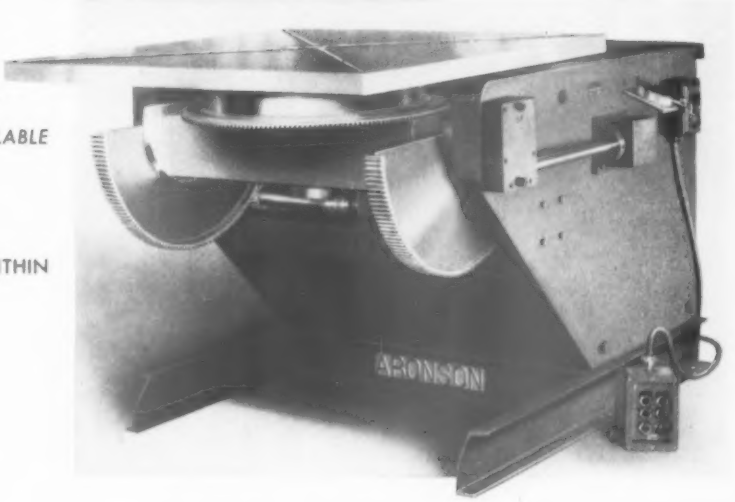
- TABLE TILT REPEATEDLY HELD TO 1°
- EVERY BEARING IS BALL or TIMKEN TAPER ROLLER



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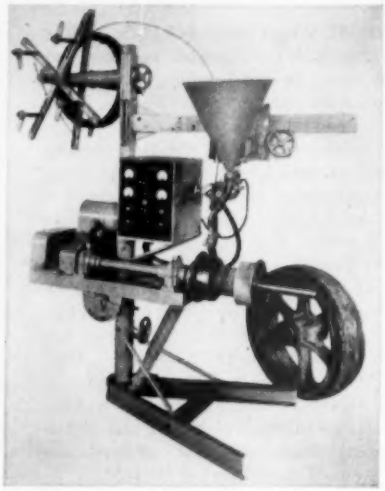
WELDING THAT IS *Really Automatic*



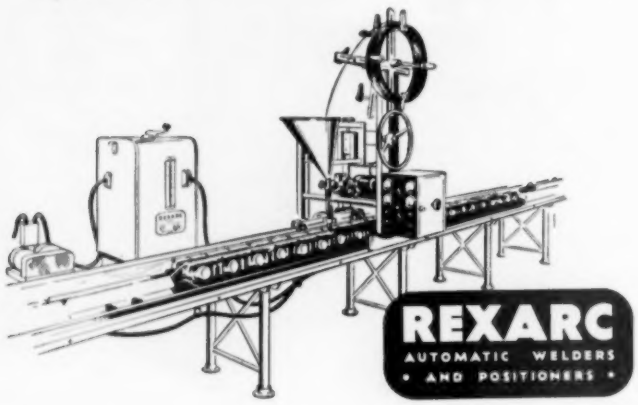
Rebuilding rollers, idlers, crusher rolls and countless other circular shapes is fast and simple—with a Rexarc Automatic Welder and Positioner.

Here's welding that is *really* automatic! Metal is deposited at a fast rate with complete control over low arc voltage and amperage, minimizing stress and dilution of the parent metal. High frequency starting and stabilization assures a steady arc. Welding can be lineal or cross-bead, continuous or in sequence.

Rexarc Welders can be equipped for automatic step-over and spiral welding and timed to operate at pre-determined speeds for any desired length of time.

REBUILDING CRAWLER TYPE TRACTOR RAILS

Welding on tractor rails and other longitudinal surfaces is accomplished easily by transferring the welding head and controls to a flat-bed positioner. On rail work, the welding arc breaks at each joint and starts automatically at the next link, depositing new metal to the desired height. Angle of the rail is automatically compensated on each succeeding pass. Metal is thus applied to the exact length and shape of the exposed link, leaving the joints free. Cutting or grinding after welding is virtually eliminated.



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THE SIGHT FEED GENERATOR COMPANY

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"A Critical Survey of Brittle Fracture of Carbon Plate Steel Structures Other Than Ships," M. E. Shank, Massachusetts Institute of Technology.

"Interest of the Army in Brittle Failures," T. T. Paul, Watertown Arsenal.

"Theory of Brittle Fracture and Criteria for Behavior at Low Temperatures," E. R. Parker, University of California

"Brittle Fracture: Significance for Engineers," S. L. Hoyt, Battelle Memorial Institute.

"Metallurgical Aspects of Low-Temperature Behavior in Ferrous Materials," C. H. Lorig, Battelle Memorial Institute.

"Fundamentals of Fracture in Metals," M. Gensamer, Columbia University.

"The Effect of Size Upon Fracturing," G. R. Irwin, Naval Research Laboratory.

"Brittleness, Triaxiality and Localization," W. P. Roop, Anchorage Farm.

"High-Speed Motion Picture Study of Impact Test," H. L. Fry, Bethlehem Steel Co.

"Evaluation of the Significance of Charpy Tests," William S. Pellini, Naval Research Laboratory.

"Significance of V-Notched Impact Test in Evaluation of Armor Plate," A. Hurlich, Watertown Arsenal.

"Notch-Bend Tests for Evaluating the Properties of Weldments," R. D. Stout, Lehigh University.

"Reproducibility of Keyhole Charpy and Tear-Test Data on Laboratory Heats of Semikilled Steels," R. H. Frazier, J. W. Spretnak and F. W. Boulger, Battelle Memorial Institute.

"Effect of Specimen Preparation on Notch-Toughness Behavior of Keyhole Charpy Specimens in the Transition Temperature Zone," R. W. Vanderbeck, W. T. Lankford, S. C. Snyder, United States Steel Corp., R. W. Lindsay, The Pennsylvania State College, H. D. Wilde, The Pennsylvania State College (now with Sharon Stationery and Supply Co.).

"Notch Sensitivity of Steels," E. J. Ripling, Case Institute of Technology.

"Tension Impact Strength and Strain Distribution at Room and Subzero Temperatures of Stainless and Other Steels," V. N. Krivobok, The International Nickel Co.

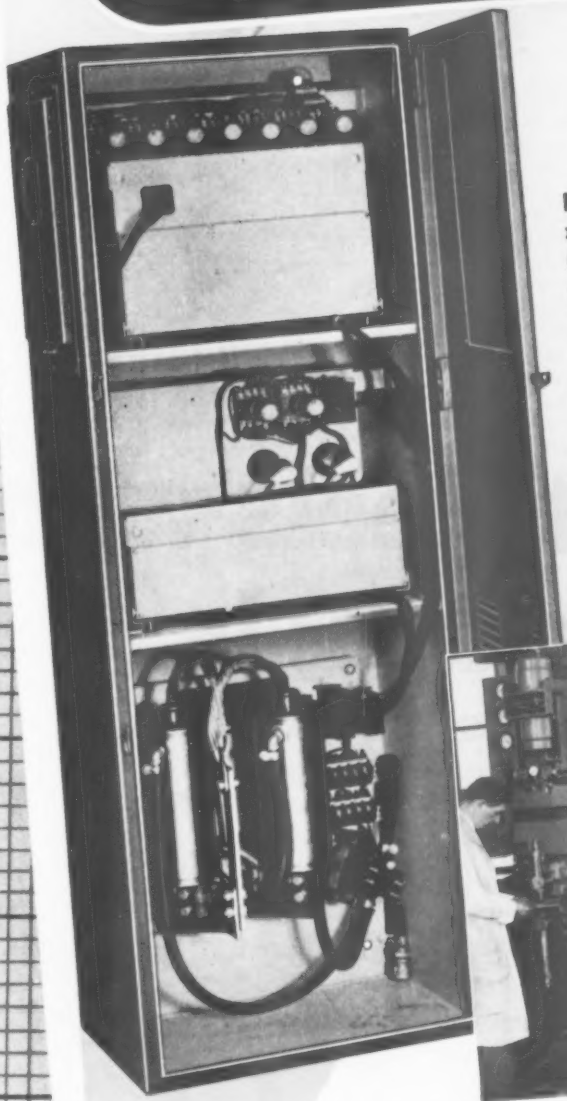
Diamond Pins Presented by Eutectic

Diamond pins were awarded recently to regional managers and district engineers of the Eutectic Welding Alloys Corp. for meritorious service and achievement by Rene D. Wasserman, president of the company.

The presentations were made at sales clinics held throughout the country by the president and the National manager, F. F. Rochill. The meetings gave the representatives the opportunity to discuss problems encountered in the field and enabled the management to brief them

Stainless Steel? Aluminum? Magnesium? Air-Hardenable Steels? Low Carbon Steels? Aluminum-Magnesium Alloys?

What's Your Precision Welding Problem?



Square D has the control to meet your exact needs!

Easier maintenance Vastly simplified circuits require fewer tubes and only one operating relay (for the air valve).

Increased dependability Components designed specifically for industrial welder service. Tube circuits are fail-safe. Initiating contacts are in isolated 24-volt circuit.

Consistent accuracy Regulated DC voltage on tube control grids compensates for supply fluctuation or tube variations.

Greater accessibility Timer, heat control, up and down slope, forge and chill temper panels—all are designed for easy inspection and maintenance, with quick fasteners and plug connectors.

Thomson Electric Welder Company Puts Square D Control to "Acid" Test

• This Thomson Welding Machine is used for experimental and "special" jobs in the Thomson laboratory. It has put Square D control to the "acid test" in scores of precision operations. It has made crack-free welds in a variety of aluminum alloys in gauge thicknesses up to .072". It has made excellent welds in air-hardenable steels and in ½" diameter steel bars.

Write for Bulletin 8993. Address Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin. Or consult your nearby Square D Field Engineer.

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Weld "difficult" steels with little or no pre-heat!

use P&H LOW-HYDROGEN ELECTRODES

P&H has the industry's most complete line of low-hydrogen electrodes — many custom-built to match the chemical analysis or heat-treating properties of a variety of alloy steels. Being hydrogen-free, these electrodes eliminate underbead cracking — little or no pre-heat is needed to get high-strength welds on problem steels, steel castings, nickel-alloy steels, chrome-moly steels, .40 carbon castings, high-hardenable steels, aircraft and similar steels. There are other important advantages, too — for example, lower cost, compared to stainless-steel electrodes formerly used on many jobs. Ask your P&H representative or distributor for all the facts. Or write for bulletin 5-26.

Chrome-moly header, typical of high-pressure, high-temperature applications.

Low-alloy casting, typical of applications where physical properties must be matched.

Alloy gear rim, typical application matching heat-treating properties of parent metal.

Excavator body, typical of heavy sections welded with P&H Low-Hydrogen Electrodes.

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HARNISCHFEGER CORPORATION
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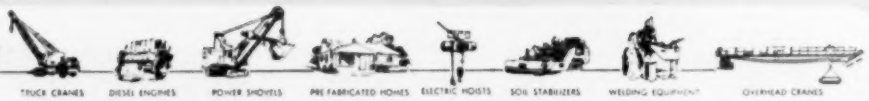
the P&H Line



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upon future policy and new products about to be released.

The ladies were entertained during these sessions by Mrs. Wasserman and Mrs. Rochill. At night a reception and dinner were held for the regional managers, district engineers and their wives.

Among those receiving diamond pins were the following members of the AMERICAN WELDING SOCIETY: Walter A. Hurleman, W. W. Shackleford, John M. Murray, Henry W. Dunlap and L. E. Woolf. Gold pins were awarded to A. P. Dervaly, Don R. Hendricks, E. E. Paine and Edwin L. Banghart, also members of the SOCIETY.

All-Welded Drill and Work-Over Barge Commissioned

The billion-dollar oil-drilling industry has just added another piece of complicated, specialized equipment for operations in the overwater oil fields of south Louisiana with the addition of the 140-ft submersible drill and workover barge, *L. A. Jett*. The all-welded steel barge was built by the Equitable Equipment Co., Inc., of New Orleans, for D. E. Vasser, Inc.

The *L. A. Jett* will be used for workover operations which consist of putting an oil well back into production after its normal flow has been reduced for some reason. Usually this consists of cleaning out, deepening or reconditioning the well so that it will once again become a good producer. Right now, such rigs are one of the greatest needs of the oil industry. The *L. A. Jett* was built in record time at the Madisonville yards of the Equitable Equipment Co., Inc.

A special feature of the *L. A. Jett* is that all the drilling and workover equipment is suitable for shore operations and may be transferred if the need should arise. The complete design of the barge was the joint effort of the marine engineers of the Equitable Equipment Co., Inc., D. E. Vasser, Inc. and the engineers of the Mid-Continent Supply Co. The barge is 140 ft long with a beam of 35 ft and a molded depth of 12 ft. It meets the specifications of the American Bureau of Shipping. Narrow width permits passage through narrow canals, locks and requires less dredging.

When the mast is up and the barge submerged with 3 ft of freeboard, the total structure rises to 153 ft above the water level. The Jackknife mast allows for easy movement under bridges, overhead obstacles, etc. Further, it need not be dismounted for movement. The hull of the barge holds the 10,000 gal of fuel oil, 24,000 gal of fresh water and the submerging tanks.

The 200-bbl active mud pit is on the main deck at the bow of the barge. Next to it, on the port side, is another 300-bbl active mud pit. D-500 and D-300 Emsco mud pumps operate from the compound on the 10-ft deck. Amidship and next to the port mud pit are two generator sets—a 30 kw Caterpillar D-315 Diesel set and a 60-kw General Motors 671 Diesel set. The main distribution switchboard which feeds to all the electrical equipment is also located on the main deck. The 8- by 74-ft key has a 230-bbl reserve mud pit on one side and a storage room on the other. The storage room holds all the hand tools, welding, burning and oxygen equipment. The key has a pollution gate which prevents oil from contaminating the water around the barge. Butane cylinders, for heating, the fuel oil transfer pumps and water distributing pressure sets, and pumps complete the primary equipment of the main deck.

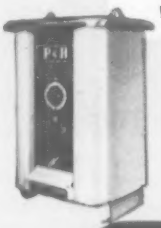
Over the key are located the pipe racks with a capacity of 10,000 ft, and on each side is a 5-ton manual pipe derrick for loading and unloading the pipe. The 10-ft deck holds the main power plants for the oil operations. These are two sets of dual Cummins NHRMS-600 supercharged Diesels with a total of 1200 hp. The main Diesels operate a U-37 compound which furnishes the power to the mud pumps, a Westinghouse five G 12-cu-ft air compres-

P&H

WELDING HEADQUARTERS

—that's where you find cost-cutting answers to welding problems

P&H AC WELDER



Any heat at your fingertips — right at the work — with Dial-lectric Instantaneous Remote Control. Sizes up to 625 amps., NEMA rated. Connectable to 220 and 440 volts.

P&H WELDING TWINS

P&H DC RECTIFIER WELDER

Right now —at the work — fingertip Dial-lectric Control gives you the heat you need. Three sizes, 200, 300, and 500 amps., NEMA rated.

P&H WN-301 *Engine-Driven* DC ARC WELDER

It's portable—weld anywhere, anytime. Dial-lectric Control gives you fingertip heat control at the work — for faster, better welding. Runs at only 1750 rpm. Welding service range, 60-375 amps., NEMA rated.

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One finger is enough to position heavy weldments for economical downhand welding. Capacities from 2500 to 36,000 lbs. — remote-control and hand-operated models.

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P&H WELDING DIVISION

HARNISCHFEGER CORPORATION

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sor and the draw works. An auxiliary gasoline-driven Curtis 88 air compressor and a Bumba 4860-B shale shaker are on the 10-ft level.

The 17-ft deck is the operating deck and contains all the equipment for oil operations and the quarters for the crew. A 133-ft rotary drill unit of the collapsible, full-view type is mounted on the operating deck. The U-20 Unit Rig draw works and Hydril blowout preventers complete the equipment.

The quarters are large enough for a crew of eight and include a lounge, galley, mess, toilet, showers and a storeroom. The crew quarters are insulated and finished with marine plywood.

Atomic Era Dividends

America's largest steel plate mill, built during World War I, continues to play a vital role in the successful design of atomic era defense measures. J. Frederic Wiese, Vice-President of Lukens Steel Co., has pointed out that Lukens plates are being fabricated into the Navy's first atomic submarines, the U.S.S. *Nautilus* and the U.S.S. *Sea Wolf*, as well as the giant 60,000-ton aircraft carriers, the U.S.S. *Forrestal* and the U.S.S. *Saratoga*.

The flat keel plates of the 1040-ft U.S.S. *Saratoga*, now under construction at the New York Naval Shipyard, Brooklyn, are fabricated of Lukens high-tensile alloy steel.

In addition to Lukens high-tensile steel shell plating, Lukens stainless clad steel is also used in the construction of atomic subs.

Keel for the Navy's giant new 60,000-ton aircraft, USS Saratoga, is laid at New York Naval Shipyard, Brooklyn

Westinghouse has everything for arc-welding anything ...anywhere

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- Complete Line of Accessories for Every Welder
- New D-C Welders with Arc-Drive Control
- Multi-Purpose, Engine-Driven Field Welders
- Complete Line of Stainless Steel Electrodes
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New Low Prices ON AIRCO WELDING WIRE

for the Aircomatic® and other inert-gas-shielded arc welding processes

Consumable, spooled wire – stainless, copper-base alloy and aluminum – now at new low prices. The following sizes are immediately available:

Airco ALUMINUM	3/64", 1/16", 3/32", 1/8" dia.
Airco STAINLESS	.035", .045", 1/16", 3/32" dia.
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For complete price list and table of all Airco wires, including chemical analyses, gauges, lengths and stock numbers, call your nearest Airco office, or write Dept. 17 WJ Air Reduction Sales Company, 60 East 42nd Street, New York 17.

Specify Airco wire for –

- Controlled, uniform chemical analysis
- Highest possible standards of surface finish, cleanliness and straightness
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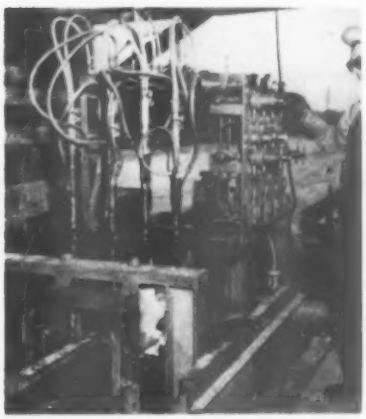
AT THE FRONTIERS OF PROGRESS YOU'LL FIND . . .

AN AIR REDUCTION PRODUCT

Pressure Welding of Rails

Existing production records for turning out oxy-acetylene pressure butt welds in rail are being topped by the Texas and Pacific Railway at Scottsville, Tex.

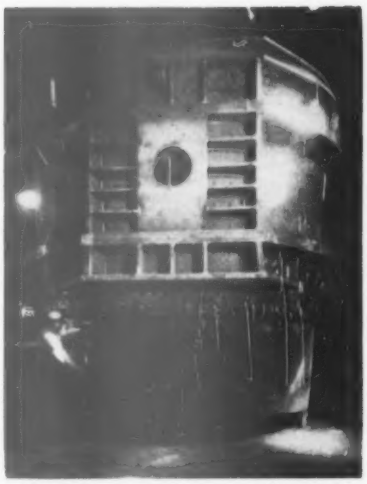
The railroad, in its present program, is producing 72-ft rails by cropping approximately 1½ ft off each end of used 112-lb rails and butt welding two of these together with Oxweld rail-welding units. Since the start of the program on January 5th, forces doing the work have averaged 62 welds per day and on one day production reached 72 welds in an 8-hr period.



One of the Oxweld rail-welding units used by the Texas and Pacific Railway

Welded Steel Ladles

The first of 18 welded open-hearth ladles of 265-ton capacity—among the steel industry's largest—is being constructed at the Bethlehem, Pa., plant of Bethelehem Steel Co. The steel ladles, more than 16 ft high and weighing 44 tons apiece, will be installed at the company's Sparrows Point, Md., plant as part of an expansion program.



The ladles are being stress-relieved after welding. In shipping, the riveted band 4 ft above the bottom will be removed from the ladle so it can be transported in two pieces.

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(Continued from page 526)

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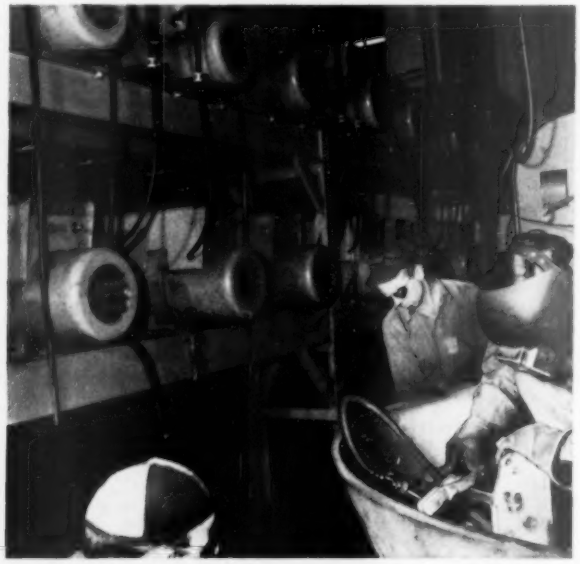
Welding Arcs

PROPER CURRENT SETTING is easy with G-E single-dial dual control. Button for magnetic starter is at far end of set.



REDUCED NOISE, INCREASED PROTECTION provided by new WD-40 sets are important factors in multiple-welder areas.

New Magnetic Starter, Quieter Fan Improve G-E Welder Performance

You receive important new benefits from today's General Electric Type WD-40 arc welders. First, you get improved welder and electrical-system protection and lower maintenance with the new magnetic starter. Second, you get reduced operator fatigue, resulting in higher production, because of the new, quieter ventilating fan.

These improvements, plus present G-E features, combine to give you this unexcelled performance:

- **STEADY ARC,** providing high penetration and minimum popouts due to a unique generator interactor which smooths out current fluctuations.
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G-E WD-40 welders are built in ratings of 200, 300, and 400 amps, for every direct-current industrial application. Your nearby G-E welding distributor can supply you with complete information. He's listed here and in the yellow pages of your phone book under "Welding Equipment—General Electric." Get in touch with him today. General Electric Company, Schenectady 5, N. Y. 710-3

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GENERAL ELECTRIC

News

Information on equipment, electrodes and accessories from G.E., pioneer in arc welding

Neutralize moisture pick-up with a DryRod oven

If you are using low-hydrogen or stainless-steel electrodes, don't sacrifice their quality by using electrodes exposed to humidity. Moisture picked up after the package is opened can cost you much of the built-in protection against under-bead cracking and porosity. The answer to this problem is a DryRod oven.

Installed at the job, this oven restores electrode efficiency and provides a convenient, dry storage place. For you this means fewer rejects and reworks, less X-ray porosity.

The DryRod Type 300 oven holds 350 pounds of 18 in. electrodes, has a temperature range of 175 to 550 degrees, yet weighs only 115 lb. See your nearby General Electric welding distributor for more details.

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Joe Magee says . . . Try W-29 rod for high-impact jobs

When welding on farm implements, road-building tools, and other equipment subjected to high impact, use G-E Type W-29 electrodes.

These Class E-6012 electrodes combine the smooth welding and minimum spatter of G-E Type W-28 electrodes with higher elongation and impact values than generally found in E-6012 deposits. It's also easier to produce more-complex fillets with W-29, for greater resistance to weld-bead cracking. And W-29's high burn-off rate means faster production.

Exceptional impact strength of W-29 deposits makes these electrodes particularly applicable for work subjected to low temperatures.

So remember, next time you have a high-impact or low-temperature application, use the electrode especially designed for the job: G-E Type W-29.

Free Electrode Book

Here's a handy reference book that you will find use for again and again on the job. It's General Electric's pocket electrode catalog which contains concise descriptive and application information on all G-E electrodes.

This useful booklet is available *only* through your General Electric welding distributor. Ask him for your free copy of GED-1634 today.

Here's the name of your G-E Welding Distributor—

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo—Hendrie & Bolthoff

Florida: Hollywood, Miami—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton—Machinery & Welder

Indiana: Evansville—Drill Master Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

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Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

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New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

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Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

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NEW PRODUCTS

Cutting Electrodes

Electrodes of special carbon-graphite composition have been developed for use with "Arcair" gouging and cutting torches. Relative qualities of Arcair carbon-graphite electrodes are compared to all-carbon or all-graphite electrodes, and details of actual performance given in a new booklet available from welding supply houses or by writing Arcair Co., 2614 Burwell St., Bremerton, Wash.

Electrode Holder

A new, 250-amp electrode holder, model AW-C, is now offered by Jackson Products, Warren, Mich. It takes electrodes $^1/_{16}$ in. through $^7/_{32}$ in. and cable sizes through 1/0, soldered or brazed; cables through No. 1 may be clamped in place.

The same heat-treated, 98% copper alloy is used in its construction which, it is claimed, has given other Jackson copper-alloy holders the utmost in strength, hardness and conductivity, yet weight is kept down to 19 oz.

Jaw insulators of an entirely new thermal-setting material have been developed to give this holder many times stronger protection at its most vulnerable points.

McKay Hard-Surfacing Electrodes

The McKay Co. announces that it is now producing a completely new line of cost cutting, hard-surfacing electrodes. These electrodes are coated with a newly developed, low-hydrogen type coating which permits easy operation on both alternating and direct currents. The use of low-hydrogen coatings assures the highest possible quality in deposited weld metal and, at the same time, keeps weld metal dilution at an absolute minimum providing the proper alloy balance on the working surface. The electrodes are packaged in hermetically sealed, moisture-proof containers to protect the coatings from moisture pickup during shipment and storage. Unit containers carry a net weight of 10 lb; a standard shipping carton consists of six unit containers.

"McKay Hardalloy" is the trade name under which the nine distinctively different grades of hard-surfacing electrodes are being marketed. To assist in the selection of the proper electrode for specific applications, The McKay Co. has issued a series of bulletins which give complete details on the operation and usability of each Hardalloy electrode grade. Specifications, chemical analysis, mechanical properties, applications and other essential data are presented for individual grades in this series of bulletins.

Copies of these bulletins are available on request. Write The McKay Co., 303 McKay Building, Pittsburgh 22, Pa., and state your specific problems to receive the Hardalloy bulletins covering your applications.

Portable Dy-Chek Kit Locates Metal Flaws

Accurate, on-the-spot inspection for metal soundness can now be made on any metal at any location through the medium of a new, all metal, portable Dy-Chek flaw location kit, according to the claims of Turco Products, Inc.

Dy-Chek materials are applied in the field in basically the same manner as they are applied in the plant. Precleaning is accomplished by wiping the area or part being inspected with a rag saturated with Dy-Chek Dye Remover. The brilliant red liquid, Dy-Chek Dye Penetrant, is then brushed onto the surface being inspected. After being allowed to dwell long enough to enter any defects that may extend to the surface of the metal, the excess penetrant is removed. This may be accomplished either by wiping with a rag saturated with the dye remover, or by brush application of dye remover, followed by a water rinse, if water is available. Since, to insure accuracy, it is a necessity to apply Dy-Chek Developer by spray, two pressurized sprayers of developer have been provided in each kit. The developer is "fogged" along the surface being inspected until a thin, even white coating of developer has been applied. The developer dries almost instantaneously, pulling the hidden red penetrant to the surface at locations where flaws exist. Cracks are indicated as brilliant red lines, while red dots indicate porosity. Depth of defects is indicated by richness and speed of bleed-back.

Complete information concerning the new Turco Dy-Chek metal inspection kits may be obtained from Turco Products, Inc., 6135 S. Central Ave., Los Angeles 1, Calif.

New Welding Machine Features Arc-Voltage Control

A new, lightweight sigma (shielded-inert-gas metal arc) welding machine, the SWM-3, features arc voltage control. This feature is said to eliminate all welding problems that are due to a fluctuating arc voltage. Electronic controls maintain the proper balance of welding conditions by instantaneously speeding up or slowing down welding wire feed rate as required by changing arc conditions. Smooth, uniform welds are claimed as a result of this precise control over welding variables.

Voltage control was developed for inert arc welding by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. The electronic control unit does not get in the way of the welding operator or other work going on in the shop. And it does not have to be moved with the welding machine from one job to another. It can be permanently mounted anywhere, as long as it is properly connected to the welding machine.

The SWM-3 is easy to operate. All that the welding operator needs to do is preset the required voltage, and throw the start-

ing switch. A retract starter built into the electronic control unit does the rest. It causes welding wire to feed down until contact is made with the work. Then the wire automatically retracts, drawing an arc; then the wire reverses direction a second time, and feeds down, maintaining the preset arc voltage.

The SWM-3 can be moved from one job to another by one person. When mounted on a wall, post or machine carriage, the SWM-3 mechanizes many welding jobs.

Flexibility is another feature of the SWM-3 welding machine. This machine can be used to fabricate most commercial metals in almost any joint design. Butt, lap, fillet and corner welds are made in aluminum alloys, stainless steels, carbon steels, deoxidized copper, Everdur and aluminum bronze in thicknesses from 16 gage. Welding wires of 1/32, 3/64, 1/16 and 1/32 in. in diam are used with the SWM-3.

For more information about this new inert-gas metal-arc welding machine, write to Linde Air Products Co., 30 E. 42nd St., New York 17, N. Y.

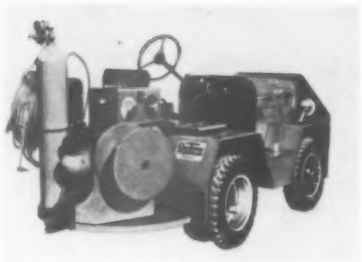
Concentrated Soldering Flux

A new extremely concentrated soldering flux for use on iron, steel, copper, bronze, brass, zinc, terne plate and many alloys is trade-named Tins-tyter. It is said to assure tinning, instant positive bonding and thorough penetration into joints and seams of heavily oxidized metals or alloys difficult to solder. Diluted with up to four parts water, it provides an equally effective and very economical flux for metals easy to solder. It is suitable for solder-iron, flame or dip soldering, requires only the minimum heat necessary to melt the solder and leaves clean lines and smooth surfaces. Flux residue can easily be removed with water. Tests indicate that soldered joints will usually resist stresses just as well as the metals themselves. Free sample for test use in your own plant may be secured from Remont Manufacturing Co., 1310 Meyers Road, Lombard, Ill. (For stainless-steel type alloys, request sample of Stainless Steel "48" soldering flux.)

Mobile Unitow Welder Tractor

Compact new Unitow welding unit pictured, moves direct to the job under its own tractor power. Carries all welding equipment, materials and men for fast on-the-spot welding anywhere.

Saves hours of time by moving quickly around industrial plants, out in the yards or between widely separated buildings. No time lost waiting for installation of electric power lines or delivery trucks. Powerful International Harvester Silver Diamond engine operates both tractor and



300- or 400-amp rated generator. Direct drive power take-off eliminates belts. Electric arc control box is conveniently mounted behind driver's seat.

The tractor is streamlined to a width of only 53 in. with single rear drive wheels (65 in. with dual drive wheels). Short 138 in. length, 118 in. turning radius and low over-all height of only 65 in. enables this Unitow Welder to navigate narrow aisles, low doorways, crowded platforms and docks. It does double duty as a powerful towing and pushing tractor for handling trailer train loads of materials, railroad car spotting, etc. Available with oxy-acetylene tank bracket and handy cable reel. Detailed bulletin on request from Hensel Green & Co., Mfrs., 9 S. Clinton St., Chicago 6, Ill.

"Octopus" Automatic Welding Machine

A new automatic welding machine, just put into operation at the Irving Subway Grating Co., Long Island City, N. Y., has been dubbed the "mechanical octopus" by plant workers.

The "octopus" bears a fleeting resemblance to its namesake because of the numerous tentaclelike, water-circulating tubes that extend from its body. It makes 62 simultaneous welds, or a total of 744 per min. This represents 24 sq ft of welded grating a minute, or 1500 sq ft an hour.

The mammoth welder is said to be one of the newest and most versatile of its kind. It is completely controlled by instrumentation by a single operator. Two

"Shortstub" ELECTRODE HOLDERS

Convert the total fluxed portion of all electrodes into weld metal —REDUCE STUB WASTE TO THE LOWEST POSSIBLE

TWO SIZES FILL ALL NEEDS

Model	Length Inches	Wt. Ozs.	Cap. Amps.	ELECTRODE Size
No. 4	8 7/8"	17	400	1/16" to 1/4"
No. 6	10 7/8"	24	600	3/32" to 5/8"

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New **BRUSH WELDING ANALYZER**

simplifies troubleshooting and preventive maintenance

WITH the new Brush Welding Analyzer you can instantly spot improper calibration or inconsistent or faulty operation of three-phase resistance welders, single-phase resistance spot, projection, and seam welding machines. Chart records, which are immediately available, show the magnitude and timing of all welding variables, and indicate faulty firing of ignitron tubes or other difficulties.

In addition, the Brush Analyzer helps you make sure you meet specifications. Side by side on the chart are the two records of welding current and electrode force . . . showing contact gage settings, precompression force, weld force, rate of rise, forge force, and time of operation in milliseconds.

Brush Analyzers save you time in welding analysis, and in studies of AC or DC voltage or currents, strains, displacements, stresses, and other static or dynamic conditions. Brush representatives are located throughout the U.S., in Canada: A.C.Wickman Ltd.,Toronto. For bulletin write Brush Electronics Company, Dept. JJ-6, 3405 Perkins Avenue, Cleveland 14, Ohio.

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BRUSH 6 ELECTRONICS

formerly The Brush Development Co. Brush Electronics Company is an operating unit of Clevite Corporation.

weeks of rigorous tests were applied in the Long Island City plant before it was placed in full-scale production. The builders of the "octopus" devoted 10 months alone to its design and manufacture to Irving specifications.

Output is so tremendous, the welder can produce enough grating in one day to completely surface the main concourse of New York's vast Grand Central Terminal.

During the multiwelding process, pressure for forging the bearing bars with the cross bars is equivalent to 100 tons. Welding temperature is approximately 2000° F. To generate the required heat, the welder uses enough electricity continuously to light five thousand 100-w bulbs.

The machine has its own water tower, with self-circulating system, for cooling transformers and conductors. Some 400 gal of water per minute are used.

Welds can be made at desired spacing points for grating openings of different sizes. This is accomplished by simple machine adjustments.

Electrode Holder

Now available, a new, cooler, lighter electrode holder for arc welding from the Welding Products Division of A. O. Smith Corp., Milwaukee, Wis. There is less

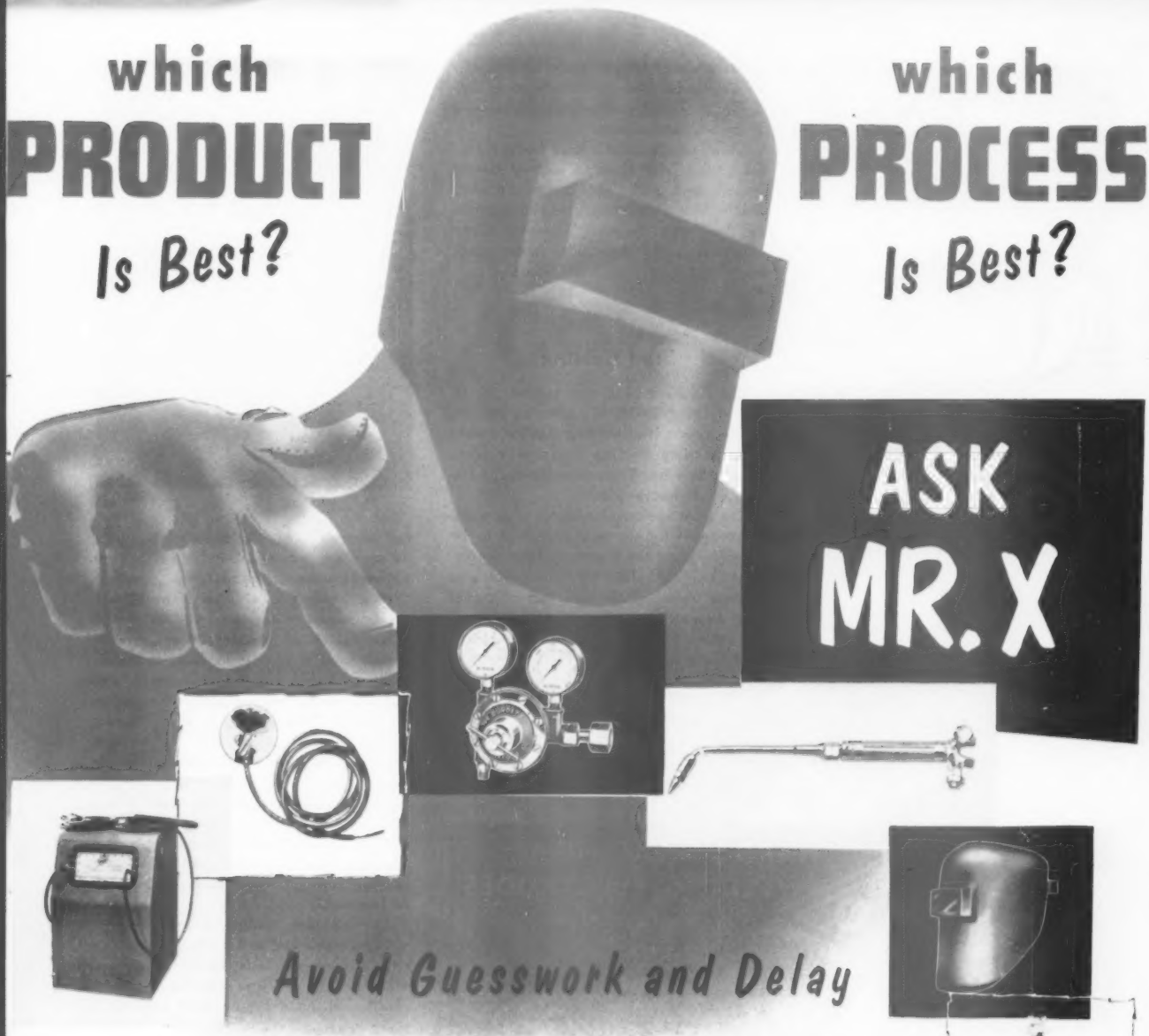
tendency for this holder to roll in the operator's hand, for the unique design places the jaw lever close to the handle, a squeeze of the hand releases the electrode stub. A fully enclosed spring and patented spring adjustment insures longer production duty. Reversible jaw insulators that can be reconditioned on the line, eliminating costly downtime is another feature of this new holder. The A. O. Smith holder is exceptionally light for the work it performs because of its channel construction, and its compound cam and lever action for parallel opening of the jaws. The coaxial springs, plus rugged construction, will give this holder a long, productive life. It is available in 200- (Model No. 2), 300- (Model No. 3) and 500- (Model No. 5) amp sizes.

X-Ray Images 1000 Times Brighter

A new X-ray Image Amplifier that supposedly produces images 800 to 1200 times brighter than those obtained with the conventional fluoroscope has been an-

which PRODUCT Is Best?

which PROCESS Is Best?



Avoid Guesswork and Delay

Mr. "X" is not one individual—rather he represents the collective experience and "know-how" of Burdox welding men. This "know-how" is the result of years of working in close harmony with companies having all types of welding problems — using all types of equipment on all types of jobs. Mr. "X" is not partial to any particular welding process . . . he is an expert in all of them and therefore in a position to suggest the best possible products *for your particular needs*.

When you buy Burdox you not only get the finest welding and cutting equipment that money can buy, but you engage the services of our Mr. "X". He will work with your workers . . . increase your output and stretch your welding dollar!

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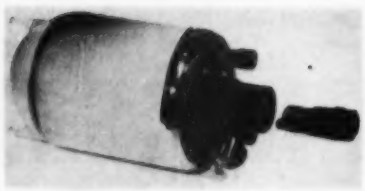

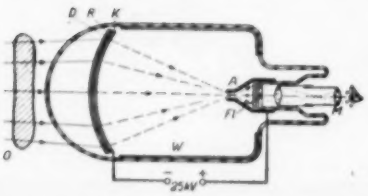

Fig. 1. Diagrammatic crossection of the image intensifier

R = fluoroscopic screen on which the X-rays are received after passing through the object to be examined *O*, and the glass wall of the tube. *D* = support of fluoroscopic screen and photocathode *K*. The fluorescent radiations produced in *R* release electrons from the photocathode *K*. The "electronic image" is reproduced on a reduced scale by the electric field between *K* and the perforated anode *A*, on a viewing screen *Fl*; this image is observed through a simple microscope *M*. *W* is a conductive layer on the inside of the tube.

nounced by the North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

Soon to be made available to the U. S. market, the new device is a development of the Philips Laboratories, Eindhoven, Holland, and is designed to improve existing fluoroscopy techniques.

When X-raying the human body, intensities must be held down so that tissues are not damaged. This forces the radiologist to work with very weak images on the fluoroscope screen. The new X-ray Image Amplifier intensifies these weak images approximately 1000 times.

Stud Welding

The issuance of a new patent (U. S. Patent Office 2,635,167) covering the use of the Nelson stud welding gun for a wide range of plug welding and drip welding applications has been announced by the Gregory Industries, Inc.

The most spectacular use of plug welding covered by the new patent is to be found in six of the country's huge continuous hot strip mills where the Nelson gun is used to fasten the fish tail on coiled strip so that there is no need for banding. Robert C. Singleton, manager of Industrial Sales for the Nelson Stud Welding Division of Gregory Industries, points out that the precise control obtained by this seminutomatic process has made it practical to plug weld the outer layers of coiled sheet in a way which holds the fish

tail securely until the material is ready for re-rolling, when the bond can be broken without damaging the material.

Plug welding is also used extensively as the means of fastening the inner and outer layers of stainless steel pressure vessels used in food processing, in installing special alloy linings and in a variety of railroad applications, one of which makes it possible to install a new type of lading anchor which is flush with the wooden boxcar lining. Grooved knockoff studs used in the latter application make it possible to stud weld in locations which would otherwise be inaccessible. When the welding is finished, the projecting end of the stud is knocked off, leaving a clear passage through which lading straps can be inserted.

In this plug-welding process, special studs are chucked in the gun, grooved so that the lower end is completely melted when the gun's trigger is pulled, leaving a shank connected to the weld only by a small neck.

In the case of joining light gage metal, the gun's energy melts not only the stud end, but the adjacent area in both pieces of metal, fusing them together.

When heavier plate is to be joined, the top plate is drilled through to provide a well for the molten stud metal.

Arc-Welding Head Shield

A new arc-welding head shield designed specifically for operator comfort has been announced by The Lincoln Electric Co. of Cleveland, Ohio. The new shield is called the Lincoln Comfort-Shield.

The feature of the shield is a permanently pliable head band made of plastic rather than the usual fiber. The adjustable plastic head band fits the head in the same way a hat does, giving a firm but comfortable fit throughout the day. The band is adjustable to fit both around and

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For complete data on this high-performance, industrial welder, and on the complete A. O. Smith machine, electrode and accessory line, see your A. O. Smith distributor or write A. O. Smith Corp., Welding Products Division, Dept. WJ-653, Milwaukee 1, Wis. *International Division: Milwaukee 1, Wis.*

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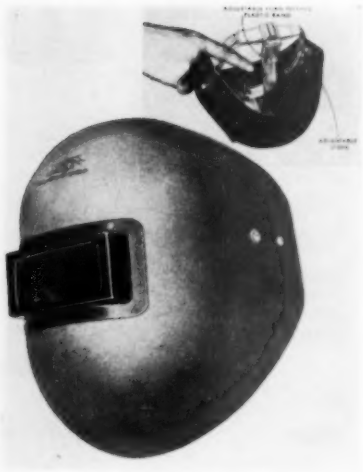


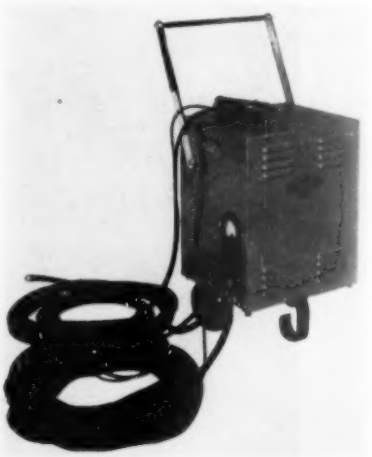
over the head, and can be put on with one hand. The plastic does not dry out and curl up as does fiber, but remains soft and pliable.

The shield proper is made with one-piece molded fiber construction which results in both light weight and strength. It has wide and deep clearance around the head to permit free circulation of air. The normal chin strap has been eliminated. Adjustable stops on each side of the head band limit the drop of the helmet to any point desired by the welder. The stops prevent the shield from hitting the nose or chin when welding vertical or overhead.

The shield takes the standard size 2-in. x 4¼-in. lens and glass.

Pin Welder

The Graham Process utilizes "stored energy" and the only power requirement necessary is 110-v., single-phase, 60-cycle current. This welder attaches steel insulation pins to air conditioning ducts over which blanket or block insulation is impaled and secured in place by a quick fastener.



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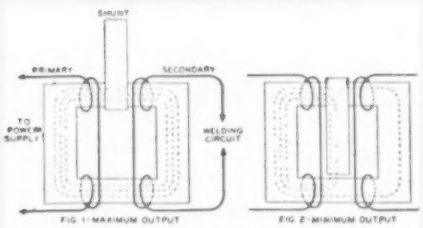
The exclusive Sureweld four-coil transformer design



The heart of the Sureweld is an exclusive 4 coil transformer that provides "long" inductive coupling, high inherent reactance, and uniformly fine welding performance. A movable core section provides stepless current control.

Sureweld® A-C SHOP WELDER IMPROVED IN MANY WAYS

The Sureweld A-C Shop Welder, for general utility welding, has always been outstanding for the remarkable arc stability it has provided, the desirable welding characteristics at all current levels and the operator's control of current value.

And now this welder has been greatly improved. The exclusive, patented 4 coil transformer has been positioned horizontally for even better ventilation and cool operation even with higher output. Primary and secondary windings are double glass-insulated (Class B) magnet wire providing higher dielectric for peak performance at high heats. Operator's convenience has been increased by side-mounting the control handle next to the high-visibility calibrated scale. Other advances markedly decrease KVA input and increase ease of operation, dependability and portability. Best of all, the improved design has resulted in lower prices.

We'd like to send you our new bulletin describing the improved Sureweld Shop Welder in more detail, or demonstrate the welder conclusively in your own shop. Available in Model S-18C, range 20 to 180 amps., and Models S-30 and S-30C, range 25 to 295 amps. Use the handy coupon now.

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☐ **Send me Bulletin NH-101 on the new Sureweld Shop Welders, for general utility welding, described above.**

☐ **Send me information on the Sureweld heavy-duty Industrial Welders for production welding.**

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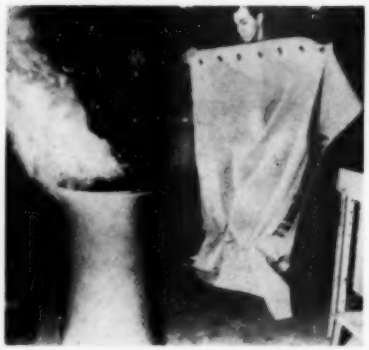
The welds do not burn through nor leave any mark on the inside of the duct sheeting. One man can apply 300 pins per hour. The gun is furnished with a cable 50 ft long, allowing for ample working radius. The cost of mounting insulation by this method reduces to approximately one-third that reflected in other similar methods of mounting. Graham Manufacturing Corp., Ferndale, Michigan.

Glass Cloth Fire Blanket

A new type vinyl plastic coated glass cloth fire blanket provides protection against fire tragedy for both human life and small industrial equipment. Manufactured by Standard Safety Equipment Co., Chicago, Ill., the extremely rugged protective blanket is thrown over a person or machine enveloped in flames; this effectively cuts off the oxygen and quickly smothers the fire.

Hung wherever possible need is greatest, indoors or out, the StaSafe All Weather Fire Blanket reportedly needs no covering to protect it from the elements. The strong glass cloth is given added strength, durability and weather protection by coating it with a plastic compound made from one of B. F. Goodrich Chemical Co.'s Geon vinyl resins. The vinyl plastic provides resistance to acids, alkalies, most solvents and other chemicals, stays flexible to below zero Fahrenheit temperatures



and will not support combustion. It gives a surface which is easily kept clean merely by flushing with water or wiping it with a damp cloth.

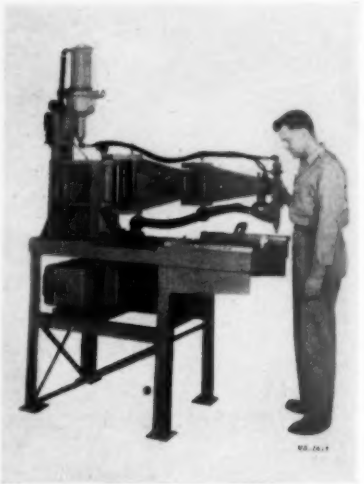
Weighing only 2½ lb the fire blanket is 76 x 60 in. in area. It is light gray in color with "Fire Blanket" printed on it in bright red so that identification is easily made.

According to Standard Safety, the new vinyl plastic covered fire blanket is approximately 30% less expensive than conventional wool fire blankets. Also the StaSafe blanket will withstand years of exposure without danger of any fire retardant washing out.

The All Weather Fire Blanket can also be used as a first aid measure in smothering fires at vents, manholes, barrels, buckets and other containers. It can be used as a welding screen, to cover fire trenches, or at any likely spot where a fire might break out.

Spot-Welding Machine

The Taylor-Winfield Corp., Warren, Ohio, announces that it is now producing a versatile, new, air-oil booster-operated spot welder designed primarily for the small metal-working shop.



Limited only by size and shape of workpieces, this new Taylor-Winfield welder supposedly can handle varied jobs without expensive tooling. However, special fixtures are available—making possible many more job combinations.

Larger plants use this new welder for production line, spot-welding work.

Anti-Spatter Compound

Thompson & Co., Oakmont, Pa., has announced development of an anti-spatter compound to increase speed and efficiency of welding operations by reducing necessary clean-up time. Designated as Thompson Anti-Spatter, the compound is brushed, sprayed or wiped along the edges to be welded and over an area extending 6 to 8 in. from the weld. When the hot spatter from the welding operation strikes the compound it will not adhere to the metal and thus can be easily wiped off without expensive grinding or power-driven wire brushes. Ordinarily, this spatter would fuse to the metal and be difficult to remove. There are two types of Thompson Anti-Spatter: No-Clean (SO-327) which provides a firm foundation for paint and requires no removal before priming; and Pickle-Off (SO-317) for use where the job is to be pickled and for use on chromium or stainless steel where ease of removal is a desirable feature. Anti-Spatter may be used in all kinds of weather. It causes no glare and has no disagreeable odor.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Application and Control

Bethlehem, Pa.—An interesting and enlightening talk on "Application and Control of Welding" was given by Roger W. Clark [M'42], Engineer in Charge of Welding Section, Turbine Division, General Electric Co., Schenectady, N. Y., at the April 6th meeting of the *Lehigh Valley* Section.

Coffee talk was given by H. N. Rahn, Safety Engineer of Ingersoll-Rand Co. and a Director of Lehigh Valley Safety Council.

The following officers were elected for the 1953–54 season:

Chairman—A. T. Barvaria.
Vice-Chairman—R. E. Somers.
Secretary-Treasurer—R.A.Bartholomew.
Directors for Three Years—H. C. VonBlohn and W. Price.

Tour of Plant

Boston, Mass.—Over 400 members and guests of the *Boston* Section on April 13th toured the plant of O. G. Kelley & Co. at Neponset, a suburb of Boston. This company also owns the Stearns Lumber Co. which manufactures the Kelley Wood Tanks and adjoins the Kelley Co. plant.

The construction of wood tanks and the automatic homogeneous lead bonding and lead burning to all types of metal were viewed in the steel shop. The Kelley Co. has the largest gas furnace for lead bonding in the industry. Their welding shop has in regular production the welding of stainless steel, Monel, cupro-nickel, aluminum, titanium and other metals. After a fine dinner the election of the following officers for the next year was announced:

Chairman—Francis L. Brandt, Jr., Thomson Electric Welder Co., Lynn.
Vice-Chairman—Louis I. Dexter, Rumford Steel Products, Inc., Providence, R. I.
Secretary-Treasurer—Herman L. Toof, Providence Steel & Iron Co., Providence, R. I.
Trustee—P. Edward McKenna, U. S. Steel Supply Division, Boston.
Directors for Two Years—Harry J. Ferguson, Metal Fabricators Corp., Waltham; Allen G. Hogaboom, Bethlehem Steel Co., Quincy; Herbert Turck, Massachusetts Engineering Co., North Quincy.

Niagara Frontier—Battle of the Sections
Left to right, judges, Rochester team, Erie team, moderator Morrison, Olean-Bradford team and Niagara Frontier team

Left to right, Bob Gehring, Westinghouse, Chairman Niagara Frontier Section; Ernie Gill, General Electric, Past-Chairman Toronto Section; Fred Perry, General Electric, Chairman Erie Section; I. Morrison, Morrison Steel Products Co., National Director at Large; Jack Gulley, George Rumble Co., Past-Chairman Toronto Section; Gomer Stelljes, W. C. Sykes Co., Chairman Rochester Section; and Charles Schuman, Dresser Industries, Chairman Olean Section

Chattanooga—Guided Tour

A. G. Kelley gave a very interesting talk on the subject "Kelley Makes—The World Takes." He described a recent business trip to Egypt and India in an intensely entertaining manner.

Battle of the Sections

Buffalo, N. Y.—The Annual Battle of the Sections sponsored by the *Niagara Frontier* Section was held on March 26. Moderator was I. Morrison [M'42] of the Morrison Steel Products Co. The teams that participated were Rochester, Erie, Olean Bradford and Niagara Frontier, with Olean Bradford as the winner.

Prior to the meeting a plant visit was made to the Morrison Steel Products Co.

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the MAN
the HEAD
EFFICIENT POSITIONING of all three
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The Weldmore Positioner and Weld-Evator enables the welder to tilt and rotate his work . . . adjust platform height . . . at the push of a button.
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Guided Tour

Chattanooga, Tenn.—On April 4th at 11:30 A.M. members of the *Chattanooga* Section met at Copperhill, Tenn., as guests of the Tennessee Copper Co. After lunch R. E. Barclay, author of *Ducktown—Back in Raht's Time*, outlined the history of the Copper Basin, a 100-sq m area in which the Copper Co. facilities and the communities of Copperhill and Ducktown are located. According to Mr. Barclay the extensive underground deposits of copper ore in the basin were discovered by early settlers in 1843 and mining began in 1850. Mining operations have been almost continuous since then. Out of more than 20 companies that have operated in the area, only the Tennessee Copper Co. established there in 1898, survives.

Groups were formed for a guided tour of the Tennessee Copper facilities. Originally producing only blister copper, the Tennessee Copper Co. has diversified its products and operations through intensive research. It is now a major producer of sulfuric acid in various grades, as a by-product from a number of operations.

Some of the facilities observed during the tour were one of the mine hoist houses, flotation plants, roaster and sinter plant, contact acid plant, copper sulfate plant and the chamber acid plant.

Of particular interest to the group were the extensive welding, fabricating and machine shops maintained by the company. Welding is widely used both in maintenance and new construction throughout the different facilities.

Welded Piping

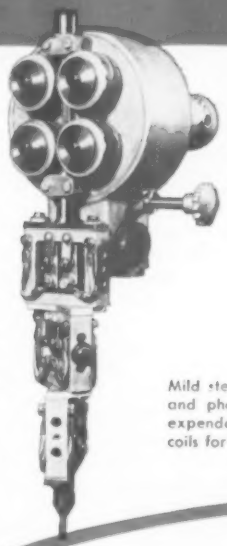
Cleveland, Ohio.—"The Design of Welded Piping" was the subject of a talk given by Frank S. G. Williams, Manager of Engineering Standards for Taylor Forge and Pipe Works, at the April 8th meeting of the *Cleveland* Section. Mr. Williams showed slides to illustrate back-up procedures and types of joints, also the various types of fittings available. Several typical piping installations were briefly discussed as well as methods of inspection, flow characteristics and codes.

Coffee speaker was W. A. Starner of the Social Security Administration who described some of the features of the Social Security Law.

Unusual Welding

Denver, Colo.—An excellent research paper on "Welding the Unusual Metals" was presented by J. E. Dato [MS], Linde Air Products Co., Kansas City, Mo., at the April 14th dinner meeting of the *Colorado* Section. New methods, applica-

Every Welding Need

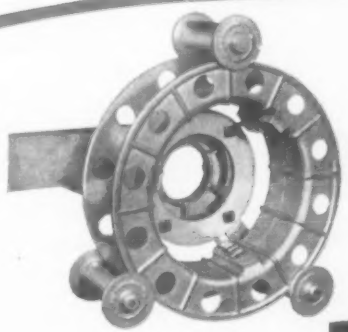


The Reid-Avery type 4R automatic head and control originally designed for Raco composite type A, may be used with equal success for lightly coated open arc or for submerged arc welding.

Raco composite type A heavy coated automatic (open arc) electrodes, a "Reid-Avery" first, can be furnished for all mild steel, low alloy high tensile, low hydrogen, hard surfacing and stainless steel grades.

Mild steel, alloy steel, stainless steel, aluminum and phosphor bronze wire are available on expendable wooden spools or in layer wound coils for gas shielded arc welding.

The Raco "free wheeling" reels are especially designed for high speed automatic machines. The ball bearing trunnions enclose the coil so there is no over-run or loose strands and larger coils can be used. Changing coils is a matter of only a few seconds and no tools are required. Available in 12, 14, 25 and 36 inch sizes, for any weight from 50 to 200 lbs.



The Raco coils of wire for submerged arc welding have long been known for their uniform high quality and convenient, easy to handle package. Special attention is paid to the accurate weight, lay and temper of the wire so that the wire will accurately follow a seam. Available in mild steel, alloy steel and stainless steel.

Since 1919 Reid-Avery Company has specialized in the manufacture of all types of welding electrodes and wire. The large modern plant in Baltimore is equipped for wire drawing, annealing, pickling, coating, cutting, winding and packaging. Every phase of welding electrode and wire production is completely controlled from start to finish. You can be assured of uniform high quality and the best possible deliveries.

We also manufacture a complete line of manual electrodes in the following grades:
Raco Mild Steel, Raco Low Alloy High Tensile, Racocast for nonmachinable welds on cast iron, Raco Feral for welding aluminized sheets, Raco Low Hydrogen, Raco Hard Surfacing, Racolloy Stainless, Racolloy Nickel and Nickel 60 for machinable welds on cast iron.

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tions and processes were covered. Slides and motion pictures were used to illustrate the talk.

Coffee speaker was Earl E. Schoel, Special Agent of the U. S. Secret Service, who gave some very helpful tips on the subject "Know Your Money."

Flame Cutting

Des Moines, Iowa.—R. F. Helmkamp AWS, Flame Cutting Specialist for Air Reduction Sales Co., described the finer points of "Mechanized Flame Cutting" to the 46 members and guests present at the dinner meeting of the *Iowa* Section held on Thursday evening, March 26th. Such Airco gas cutting machines as the Planograph, Monograph, Oxygraph, Travograph and Radiagraph were explained. Mr. Helmkamp pointed out that straight line, circular or arc, bevel and irregular outline cutting can be efficiently performed by any of these machines. Of particular interest were the various tracing devices that can be furnished for a particular cutting operation. Mr. Helmkamp's discussion was supplemented with excellent colored movies and slides.

Welding of Aluminum

Erie, Pa.—An excellent discussion on "Welding of Aluminum and Its Alloys" was covered by W. M. Rogerson, Aluminum Company of America, at the monthly dinner meeting of the *Northwestern Pennsylvania* Section held on April 16th at the GE Community Center. Mr. Rogerson used slides and motion pictures to illustrate his subject.

"Tool and Die Welding" was the subject of the coffee talk given by A. Patterson of Pat's Welding Co.

Plant Tour

Fort Wayne, Ind.—The March 20th meeting of the *Anthony Wayne* Section was held at the Central Soya Co., Inc., plant in Decatur, Ind. C. I. Finlayson, Plant Manager, showed a film entitled "When Tillage Begins" which depicted the link from farm to the manufacturer of the soya bean and showed the many uses of the product. A superb chicken dinner was served to the 47 members and guests by the ladies of the Zion Evangelical Church.

During the plant tour the members saw a link-belt freight car unloader that unloaded a car of beans in 3 minutes and is able to handle soya beans from 14,000 acres in 24 hours. The next stop was the steam power plant that puts out two million pounds of steam and 84,000 kw of electricity every day.

The Central Soya Co. has one of the largest repair shops in the State of Indiana and from this shop a complete solvent plant was built.

Annual Spring Symposium

Grand Rapids, Mich.—The *Western Michigan* Section held its Annual Spring Symposium on Friday, April 17th, at the Grand Rapids Public Museum. The Symposium opened at 9:00 A.M. with words of welcome by J. H. Blankenbuehler, District Vice-President. Two speakers and subjects were presented at the morning session as follows:

A. K. Pandjiris AWS, President, Pandjiris Weldment Co., St. Louis, Mo. Subject: "Jigs and Fixtures for Welding."

C. W. Middlestead AWS, C. W. Middlestead Co., Upper Darby, Pa. Subject: "Fundamentals of Resistance Welding."

The afternoon session was opened by National President F. L. Plummer who spoke on the scope and objectives of the AWS. Three speakers and subjects were presented in the afternoon as follows:

L. C. Bibber AWS, Welding Engineer, U. S. Steel Co., Pittsburgh, Pa. Subject: "Residual Stress and Distortion."

H. E. Baldwin AWS, Process Engineer, R. G. Le Tourneau, Inc., Peoria, Ill. Subject: "Applications of Manual and Automatic Submerged Arc Welding."

T. B. Jefferson AWS, Editor of *The Welding Engineer*, Chicago, Ill. Subject: "Design for Arc Welding."

The Executive Committee gave a dinner for the committee, their wives and speakers. The final event of the evening was a get-together at Chairman Carl Van Loo's.

In conjunction with the Symposium, the Section sponsored a display of welded products in the main auditorium of the Museum during the week.

Magnesium

Houston, Tex.—An extemporaneous discussion on "Fabrication and Application of Magnesium Wrought Products" was given by Ray L. Nelson AWS, Dow Chemical Co., Midland, Mich., at the April 22nd dinner meeting of the *Houston* Section held at the Ben Milam Hotel. Before the discussion a film entitled "Working of Magnesium" was shown through the courtesy of the Dow Chemical Co.

Titanium

Indianapolis, Ind.—A double-feature program on synthetic jewels and new developments in metallurgy was presented by the *Indiana* Section on Friday evening, March 27th, at the Athenaeum.

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Chicago Stadium Engineer
And that's not all—This Trindl 160A Arc Welder saved the Stadium thousands of dollars in time and labor costs. These low cost, high-quality welders are designed to handle production work with perfection eliminating costly work stoppage as Mr. Murray's letter testifies.
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This is an actual photo of the Trindl 160A Welder in operation on the Chicago Stadium job. Complete details and illustrated literature on the remarkable performance of the Trindl Constellation line available. Contact your local dealer or write Dept. T50-F for information.
There is a Trindl Constellation Welder to suit every job at a cost to fit every budget. 8 Models from 30 to 400 Amperes unconditionally guaranteed for 12 months.
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The first part of the program was presented by C. A. Heffernon (M'52), Linde Air Products Co. Mr. Heffernon discussed the making and cutting of synthetic gems, after which a motion picture entitled "Modern Gem Cutting" was shown.

The second part of the program was given by Lee S. Bush, Metallurgist of P. R. Mallory & Co., on "Titanium and Metal Ceramics."

Ladies were also invited to this meeting. A total of 68 members and guests were present.

New Metals

Kansas City, Mo.—At the regular meeting of the *Kansas City* Section held on February 12th Glenn A. Fritzlen, Assistant to Technical Director, Haynes Stellite Co., gave an interesting discussion on 70 new metals including the history, composition and application for each.

Plant Tour

Kansas City, Mo.—A 90-minute tour of the new Midwest factory at the Ford Aircraft Plant in Claycomo, Mo., took place on March 12th. Fifty-nine members of the *Kansas City* Section saw first hand the special methods, tools and materials involved in the fabrication of wings for the B-47 jet bomber.

Old Timer's Night

Kansas City, Mo.—The April 9th meeting of the *Kansas City* Section was held in honor of E. D. "Andy" Anderson, a charter member of the Section, who has just retired from The Lincoln Electric Co.

Ray Townsend, Chairman of the National Membership Committee and an old friend of Andy's, gave a short talk on his relationship with Andy and also an interesting summary of Andy's activities in industry and the AWS. Ray closed his talk by reading an original composition entitled "An Ode to Andy."

Left to right, Francis Stevenson, Chairman of the Aircraft and Rocketry Panel; Herbert Clemens, Chairman of the Los Angeles Section; William Immenschuh, Ryan Executive Engineer; and Earl D. Prudden, Ryan Vice-President

Les Williams, another old-time friend and Section Technical Adviser, gave more accounts of Andy that made him better known to all.

Chairman Payne presented Andy with a desk pen as a token of appreciation of his services.

After a short recess a color sound movie on "Carbon" was shown. The film showed a method of manufacture of rods for electric furnaces and included several scenes showing the starting of an electric furnace.

Aircraft and Rocketry Panel

Los Angeles, Calif.—One hundred and ten members of the *Los Angeles* Section were present at the March 13th Aircraft and Rocketry Welding Panel held at the Ryan Aeronautical Co. in San Diego. The dinner and meeting took place in Ryan's Cafe followed by a tour of the Ryan plant.

William Brotherton, Public Relations Coordinator, gave a comprehensive account of the company's past achievements and their present activities in airframe components and electronics, piston, jet and rocket engines, high-temperature metallurgy and ceramic coatings. It was pointed out that Ryan's long experience with exhaust systems particularly fitted them for the problems connected with high-temperature sheet metal components of jet engines.

A wide variety of welding and forming operations including spot and seam welding of 618 aluminum external fuel tanks, aluminum floor beams and afterburners and various Inconel nozzles, were shown during the tour of the plant. Submerged arc welding was demonstrated on turbine frame flanges and inert-gas-shielded consumable electrode welding on Type 347 stainless steel couplings were seen being welded at very high production rates. Other operations included in the tour were the construction of refueling pods for the C-97 Stratofreighter, stretch forming and postweld annealing.

Resistance Welding Electrodes

Louisville, Ky.—A. F. Wood (M'52), Chief Product Engineer, Welding Division, P. R. Mallory & Co., Inc., Indianapolis, Ind., spoke on "Resistance Welding Electrodes, Materials and Their Applications" at the March 24th meeting of the *Louisville* Section.

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Product Design for Welding

Newark, N. J.—The important factors and considerations involved in designing products for welding were covered in a talk given by T. B. Jefferson [M], Editor of *The Welding Engineer*, at the regular monthly meeting of the *New Jersey* Section held on April 21st at the Essex House. The subject was well presented and emphasized many phases of design that can assist in improving and expanding welding.

After graduation from the University of Kansas as a Mechanical Engineer, Mr. Jefferson became Assistant Plant Engineer for the U. S. Engineers in 1933. In this position he was in charge of what was at that time "The World's Largest Maintenance Welding Shop" at Fort Peck, Mont. Mr. Jefferson was made Editor of *The Welding Engineer* and *Welding Encyclopedia* in 1940. He is AWS District Vice-President of District No. 5.

Past-Chairman George Nigh was the dinner guest. A movie of general interest entitled "Pipe Line to the Clouds" presenting the story of America's water supply and its associated problems was shown. This outstanding film was prepared by the General Electric Co. and a U. S. Government Agency and was acclaimed at the International Film Exposition in Milan, Italy.

Low-Alloy Steels

New York, N. Y.—D. L. Mathias, Research Engineer, Arcrods Corp., Sparrows Point, Md., spoke on April 14th to an audience of *New York* Section members and their guests. His subject was "Developments in Welding Low-Alloy Steels." The program was preceded by dinner at Schwartz's Restaurant, 54 Broad St., New York, where the New York Section's meetings are regularly held.

Mr. Mathias' paper presented a discussion of the advantages of lime-ferritic, or low-hydrogen type, electrodes. He explained their development and the most suitable fields of application for this type of electrode. It was pointed out in this paper that these electrodes have been offered to the industry as a supplement to conventional electrodes, and cannot be expected to be a panacea for every welding problem. However, many steels previously considered unweldable are now successfully welded with low-hydrogen electrodes. Mr. Mathias discussed the operating characteristics of these electrodes, and spoke of the necessity for proper packaging and storage to maintain the moisture content of the coating at the optimum level. The paper was illustrated with slides which pointed up the metallurgical aspects of Mr. Mathias' paper.

Welding Difficult Steels

Oklahoma City, Okla.—A discussion of the effect of welding variables and the resulting weld joint in terms that can be appreciated by the "Man Behind the Mask" was covered in an excellent talk given by Howard N. Simms [M], Black, Sivalls & Bryson, Inc., at the March 27th meeting of the *Oklahoma City* Section. Mr. Simms' talk was a preparatory step in aiding the welding operator as well as the supervisor and the engineer to gain the maximum from the Educational Welding Conference which was held under the auspices of the Oklahoma City Section and the University of Oklahoma on April 21st, 22nd and 23rd.

Submerged Arc Welding

Pascagoula, Miss.—New developments in submerged arc welding were covered in a talk by Norman G. Schreiner [M], Linde Air Products Co., New York, at the April 1st meeting of the *Pascagoula* Section.

A sound color film entitled "The Shining Heart" was shown through the courtesy of the Allegheny-Ludlum Steel Co.

Welding of Steel Castings

Peoria, Ill.—A semitechnical discussion of the subject "Welding of Steel Castings" was given by James H. Lowe, Steel Founder's Society of America, at the April 15th meeting of the *Peoria* Section.

Election of Officers

Philadelphia, Pa.—The following officers have been elected by the *Philadelphia* Section for 1953–54:

Chairman—Ralph D. Bradway, New York Shipbuilding Corp., Camden, N. J.

First Vice-Chairman—R. David Thomas, Jr., Arcos Corp., Philadelphia.

Secretary—A. John Erlacher, United

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Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

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The Arcair torch, which gouges, cuts, grooves and bevels all metals using only electric arc and compressed air, will be exhibited at the National Welding Show at Houston, June 15-19. Daily demonstrations of cutting and gouging with the Arcair torch will be made under the direction of M. D. Stepath, partner in the Arcair Company, Bremerton, Wash.

Welding supply houses and their salesmen, who are dealers for Arcair torches and electrodes throughout the Southwest, have been invited to participate in the demonstrations. Show visitors can see the Arcair torch in actual operation, in typical applications involving mild and stainless steel, bronze and other metal.

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Jet Engine Welding

Pittsfield, Mass.—P. Gordon Parks AWS, Chief Welding Engineer, Solar Aircraft Co., was the main speaker at the April 2nd meeting of the *Northern New York* Section held at the Stanley Club. In his talk entitled "Jet Engine Welding," Mr. Parks specifically covered resistance and arc-welding applications on jet engine production. He is well qualified to speak on this subject and has published several technical papers.

Mr. Parks became associated with the Solar Aircraft Co. at Des Moines, Iowa, in 1945 as Welding Design Engineer.

He is Past-Chairman of the Des Moines Chapter of the American Society for Metals and Chairman of the AWS Iowa Section.

Production Electrical Welding

Rochester, N. Y.—The March 16th meeting of the *Rochester* Section featured three outstanding speakers.

The first speaker was Harry Bichsel AWS, Westinghouse Electric Co., who opened his talk with a history of submerged arc welding and continued with the various types of joints to be welded. Mr. Bichsel detailed the various techniques including a-c and d-c voltages and their effects, the limitations to the speed of travel as well as the calculations for the rate of burn-off of electrodes. The heavy initial outlay and the economics of the process were emphasized.

The second speaker was John McKenzie AWS, Linde Air Products Co., who introduced his talk on inert arc welding with a discussion of the various steels and their production. Mr. McKenzie gave details of the Heliarc and sigma welding processes and their effects when used in welding the various steels outlined earlier. The speaker offered the thought that the sigma process was bound to increase in scope and develop wider usage.

The last speaker of the evening was Phillip Worden, Rochester Products Division, General Motors. In his discussion of resistance welding, Mr. Worden covered in detail the welding of strip steel as carried on in their operations. In his interesting discussion he explained the various stages in the production of small diameter steel tubing from strip material.

Student Talks on Welding

San Francisco, Calif.—The *San Francisco* Section was honored to have as its coffee speaker at its March 30th meeting, J. G. Magrath, AWS National Secretary, who spoke briefly on SOCIETY matters of interest to all.

R. C. Wiley, Head of the Welding Department of California State Polytechnic College, introduced four of his Senior Mechanical Engineering students as speakers at the meeting:

Charles Meinhart who served in the U. S. Navy during the last war and in the Korean conflict, is finishing his fourth year at Cal Poly. Mr. Meinhart covered the subject "Determination by X-ray of Weld Defects and Their Effect on Joint Strength."

Walter Pouliot who also served in the U. S. Navy during the last war has been at Cal Poly since 1949. Mr. Pouliot presented Part I, "Basic Orange Peel Method," a 15-minute talk on the subject "Plate Layout for Welded Spherical Vessels."

Part II, "Expanded Cube Method," a 15-minute talk, was given by Charles Zwissler who has been at Cal Poly since 1950.

"Basic Factors in the Design of Jigs and Fixtures" was the subject of the final talk given by Claude Ferguson who served in the U. S. Army during the last war and took part in the Korean conflict. He has been at Cal Poly for the past 3 years.

Each of these excellent talks was illustrated by slides, mounted drawings and plastic models.

Resistance Welding

Sheffield, Ala.—The *Tri-Cities* Section held its regular monthly meeting on March 26th in the TVA Auditorium at Wilson Dam, Ala.

A very interesting talk on "Induction Heating, Resistance Welding and Soldering with Natural Gas and Air" was given by J. W. Kehoe AWS of the Westinghouse Electric Co.

Round-Table Discussion

South Bend, Ind.—An informal round-table discussion with Chairman G. H. Fetherston as moderator and John Grodrian AWS, and Donald Kyler AWS, as the experts was scheduled by the *Michiana* Section on April 16th. Miscellaneous subjects were covered by the experts and the members were quite pleased with the outcome.

Safe Practices

Toledo, Ohio.—The efficiency of the program committee of the *Toledo* Section was put to a severe test by a late cancellation of the scheduled March 12th Plant Visitation. In spite of the short notice, a fine program was arranged. Ralph Stentz AWS of Airco gave a timely talk on "Safe Practices in the Use of Oxygen and Acetylene." This was aptly illustrated by slides. Following Mr. Stentz's talk a 16-mm sound film covering the processes of arc-weld electrode manufacture was viewed by the 20 members and guests present, and a lively question-and-answer session was engaged in before the meeting adjourned at 10:00 P.M.

The Toledo Section meets on the second Thursday of each month at Link's Cafeteria. A dinner session is held from 6:30 to 7:30 with the meeting proper convening at 8:00 P.M.

General Welding Practices

Tucson, Ariz.—Barry Hunsaker, Field Project Engineer of the El Paso Natural Gas Co., currently working in the Flagstaff, Arizona, area, was the principal speaker at the regular meeting of the *Tucson* Section held on April 21st.

Mr. Hunsaker, a graduate of the University of Arizona, has been employed by the El Paso Natural Gas Co. for the past 7 years and helped to develop the welding process and procedures for the company as well as writing many of their welding specifications for pressure welding.

A. "Gus" Wieden, Manager of the Arizona State Employment Service, was introduced as the first coffee speaker to appear before the Tucson Section. Mr. Wieden spoke on the operation of the local employment office and also related a short history of welding in the Southwest and its relationship to his work.

Code Qualification

Wichita, Kan.—A plant tour of Mid-Western Industries, Inc., preceded the regular monthly meeting of the *Wichita* Section on March 16th. After-dinner feature was the showing of a movie entitled "Prairie Wings" which was loaned through the courtesy of the City Library.

The balance of the evening was turned over to a very capable speaker, David I. Grand AWS of the Tulsa Testing Laboratory, who discussed "Code Welder Qualification."

Shipyard Welding

York, Pa.—An outstanding technical discussion was given by S. Baum AWS, Shipyard Welding Engineer of the Philadelphia Naval Shipyard Naval Base, at the April 8th meeting of the *York-Central Pa.* Section. Mr. Baum has worked with the Navy since 1940 as Naval Architect, Mechanical Engineer and Welding Engineer. He has been Shipyard Welding Engineer at Philadelphia Shipyard since 1947.

At this meeting there was a general election of officers with the following results:

Chairman—Frank A. Logue, Alloy Rods Co., York.

Vice-Chairman—Paul Stumpf, S. Morgan Smith Co., York.

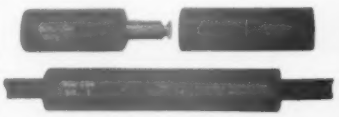
Secretary—Earl Jennings, S. Morgan Smith Co., York.

Treasurer—Charles Allen, A. B. Farquhar Division, York.

Directors for Two Years—C. F. Renshaw, Renshaw Associates, Harrisburg; W. M. Zinkand, Frick Co., Waynesboro; Wm. DeLong, McKay Co., York; W. W. Lilley, Carew Steel, York; Gordon Appleby, Lincoln Electric Co., York; Chas. McNulty, New Holland Machine, New Holland.

Directors in Office for Next Year 1953-54)—Don McDivitt, Posey Iron Works, Lancaster; Marvin Silberger, ACCO, York; Lou Ames, Airco, Harrisburg; Blair Buchanan, Standard Steel, Milroy; Paul Lang, Areway Equipment, Honeybrook; Charles Pyle, Lukens Steel Co., Coatesville.

S. Baum



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TWECO PRODUCTS

abstracts of CURRENT WELDING PATENTS

Prepared by V. L. Oldham

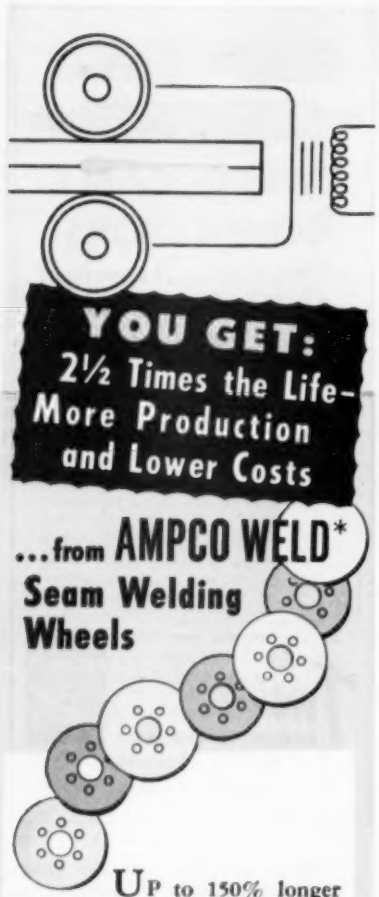
Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,632,944—PROCESS FOR CONTROLLING WARPAGE IN IRON CASTINGS DURING WELDING—Le Roy O. Kittelson, Tracyton, Wash., assignor to Engineering Development Corp., Bremerton, Wash., a corporation of Washington.

This patented process relates to the welding of cast-iron engine blocks having a crack in the upper portion thereof and comprises preheating the entire engine block to approximately 900° F and then preheating a substantial portion of the upper part of the engine block in the vicinity of the crack to a temperature of between 1100 to 1600° F. Next the crack in the engine block is welded after which the entire block is heated to a temperature of approximately 900° F and the portion of the block in the vicinity of the weld is heated to a temperature of 1100 to 1600° F and the entire engine block is permitted to cool slowly.

2,633,633—BRAZING OF AUSTENITIC FERROUS METALS—Harold N. Bogart and Donald C. Hart, Detroit, Mich., assignors to Ford Motor Co., Dearborn, Mich., a corporation of Delaware.

A process of brazing austenitic ferrous alloys with a copper base brazing material is covered in this patent. The process comprises placing at or near the joint of the parts to be secured together a supply of copper base brazing material and heating the assembly in a dry, neutral or reducing atmosphere to 1850 to 2300° F. Such elevated temperature is held in a protec-



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tive atmosphere until substantially all of the brazing metal has been absorbed into the austenitic metal.

2,634,196—IGNITING DEVICE FOR OXYGEN CUTTING LANCES—Jean Pennecot, Singapore, assignor to L'Air Liquide, Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude.

The patented igniting device includes a hollow cylindrical body closed at one end and adapted to cap the end of an oxygen cutting lance, and a percussion igniter is in the body. Combustible material previous to oxygen is provided in the hollow body and in contact with the igniter. Additionally, means for percussing the igniter are provided and are carried by the cylindrical body.

2,634,353—CURRENT CONTROL FOR TRAVEL HEAD STRIP SEAM WELDERS—Albert R. Geiszler and Leroy R. Conklin, Warren, Ohio, assignors to The Taylor-Winfield, Corp., Warren, Ohio, a corporation of Ohio.

This patent relates to apparatus for initiating and terminating a welding operation of a travel head seam type welder of the type having a flat support for strip to be welded, and a movable welding head adapted to traverse the support to perform a welding operation on strip supported thereon. The patent particularly relates to means for controlling the welding action dependent upon the position of a strip detecting member carried by a vertically movable carrier on the travel head.

2,634,354—SEAM WELDING MACHINE FOR PIPES—Henry B. Trombley, Bay City, Mich., assignor to The Michigan Pipe Co., Bay City, Mich.

In the seam welding machine of this patent, an elongate trackway is provided which has a welding unit movably mounted on the trackway, and an anvil mounted beneath the welding unit for supporting a cylindrical pipe blank. Means are provided on the machine to support one end of the anvil and hold it in its operative position but being movable to lower the end of the anvil and swing it out of engagement with the machine to allow the loading and unloading of the pipe blank.

2,634,355—ARC WELDING SYSTEM—Dean C. Girard, San Leandro, Calif., assignor, by mesne assignments, to National Cylinder Gas Co., a corporation of Delaware.

Girard's patent is on a system for controlling the energization of an intermittently loaded power circuit wherein a line contactor is provided for connecting the power circuit to a current source, and a start relay is provided which when de-energized aids in closing the line contactor and is energized by short circuiting the power circuit when the line contactor is open. A high-frequency generator is connected to superimpose high frequency on the power circuit and it is started in operation by closing of the start relay. Other relay means function to complete the energization circuit for the line contactor when the start relay is de-energized. Yet other relay means are so connected as to be responsive to the removal of load from the power circuit to stop further operation of the generator and to de-energize the line contactor upon the removal of load from the circuit.

2,634,356—GRIPPING DEVICE FOR WELDING ELECTRODE HOLDERS AND THE LIKE—Albert M. Candy, La Grange, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

This patent is on the combination of a pair of cooperating pivotally positioned jaws and means for moving the jaws relative to each other to grip an object therebetween. The gripping surface of one of the jaws is an involute of a base cylinder whose longitudinal axis coincides with the pivot axis of the jaws, and the gripping surface of the other jaw is formed complementary to the gripping surfaces of the first jaw.

2,634,633—ANNULAR SEGMENTAL WELDING HEAD—Oliver R. Smith, Fort Worth, Tex.

This patent upon a welding head relates to a clamp ring formed of sections hinged together so that the clamp ring may be closed and secured about a pipe or be opened, as desired. The ring includes sections which have internal chambers and a flexible hose connecting the chambers. Nozzles are provided on the sections of the ring and have free ends directed toward the pipe surrounded by the welding head. A fuel inlet connection is provided for one of the internal chambers, at least.

2,635,165—SKIP WELDING CONTROL—Stuart M. Spice, William F. Williams, Jr., and Wilbur E. Moehring, Flint, Mich., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This apparatus relates to welding means for producing a plurality of spaced welds between parts to be secured together. A weld rod is provided and has means for moving it toward the parts, and means for moving the parts continuously past the rod. Other means intermittently apply welding current to the rod, and timing control means are provided to de-energize the welding rod feeding means prior to cessation of welding current. A second timing control means delays re-energization of the rod feeding means for a predetermined time after the weld current has ceased to flow. Control means causes the rod feeding means to operate slowly to cause the rod to approach the parts prior to the termination of the interval in which the welding current is not applied to the rod.

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2,635,166—Welding Electrode—Sven Svantesson, Stockholm, Sweden, assignor to Allmanna Svenska Elektriska Aktiebolaget, Vasteras, Sweden, a Swedish corporation.

The patented welding electrode is for use in the arc welding of low-alloyed iron or steel. The electrode comprises a core wire having a carbon content of from 0.13 to 0.25%, and a coating over the core containing iron powder between 20 and 80% of the coating material. The coating is quite thick so that the total cross section of the electrode is between four to nine times the cross section of the core wire.

2,635,167—Method of Spot Welding—Ted Nelson, San Leandro, Calif., assignor to Gregory Industries, Inc., a corporation of Michigan.

Nelson's spot-welding method comprises placing a plate and a body member in contacting relation and the end of a fusible electrode is brought adjacent to one of the members at the site of the weld. The electrode and one of the members are connected in an electrical circuit in series to cause an electric current to flow between the electrode and the member to produce an arc sufficient to melt the end of an electrode and the adjacent portions of the plate and body members. Then the current is interrupted and the end of the electrode is driven into the molten portion of the members.

2,635,573—Pipe Welding Machine—Robert H. Taylor, Perkins, Calif., assignor to Sacramento Pipe Works, Sacramento, Calif., a corporation of California.

This machine includes a frame having a hollow mandrel positioned thereon with a continuous longitudinally extending fin upstanding from a part of the length of the mandrel. Rolls are disposed on the frame for mating with the mandrel for urging a pipe section toward and against the mandrel. A conveyor chain is supported on the frame and is used for advancing a pipe section along the mandrel to a welding station on the mandrel beyond the fin. Additional rolls on the frame press the advancing pipe section toward and against the mandrel and the fin, and a welding device is provided on the frame in cooperative relationship with the mandrel at the welding station.

2,635,926—Welder's Chair—William Michalowski, Chicago, Ill., assignor to United States Steel Corp., a corporation of New Jersey.

This special chair has a pair of runners joined at their forward ends and diverging rearwardly, and a seat and back support portion are provided at the rear portion of the runners. The seat is so arranged that an unobstructed work area is provided ahead of the seat and between the runners.

2,636,101—Arc Welding Electrode—Leland A. De Pue, Takoma Park, Md.

In this patent, an uncoated electrode is provided from a zinc-free alloy which consists essentially of about 10% tin, between about 0.4 and 0.41% phosphorus and the balance copper.

2,636,102—Automatic Metal Arc Welding System—Roscoe R. Lobosco, Elizabeth, N.J., assignor, by mesne assignments, to Union Carbide and Carbon Corp., a corporation of New York.

This patent relates to a circuit for automatically controlling the rate of rod feed in an arc-welding system and it includes a rod feed motor, one thyratron whose output controls the speed of the rod feed motor and means controlling the output of said thyratron and including a member for applying to the input circuit of the thyratron a positive voltage of such magnitude that the thyratron delivers a current which drives the rod feed motor at approximately the correct speed to maintain a desired arc voltage. An additional member is provided for applying to the thyratron input circuit a voltage proportional to the difference between the desired arc voltage and the actual arc voltage, while yet additional means apply to the input circuit a negative voltage proportional to the speed of the rod feed motor so that the actual arc voltage is maintained substantially at the desired value.

2,636,103—Welding Electrode—Jose Vazquez-Arias, Bogota, Colombia.

The weld rod disclosed in such patent has a special coating composition thereon which has been subjected to an atmosphere of gaseous carbon dioxide.

2,636,104—Electrical Apparatus—Everett C. Hutchins, Dayton, Ohio, assignor to General Motors Corp., Dayton, Ohio, a corporation of Delaware.

Hutchins' method relates to the bonding of a flat-sided tubing to an extensive metal surface. The method includes forming the tubing into a serpentine shape with long straight passes and with one of the corners of the tubing projecting into contact with a hypothetical plane which would contact one side of the serpentine-shaped tubing. The serpentine-shaped tubing is then placed upon the extensive metal surface with one corner contacting the surface and forces are progressively applied to the corner of the tubing to force each of the long straight passes of tubing into contact with the metal surface. An electric current is passed at a sufficient rate between the tubing and the metal surface at each point of progressive forcing of the corner into contact with the metal surface to weld the long straight passes of the tubing to the metal surface.

2,636,105—Welding Apparatus for Plowshares—Orwell W. Brown, Port Credit, Ont., Canada, assignor to Massey-Harris Co., Ltd, Toronto, Canada, a corporation of Canada.

Brown's apparatus is of a special nature and includes a main frame rotatably mounted on a base member and with holding means being provided for securing the main frame in either of at least two positions. A special holding jig is secured to the main frame and includes members for securing pieces to be welded in desired relationship to each other.

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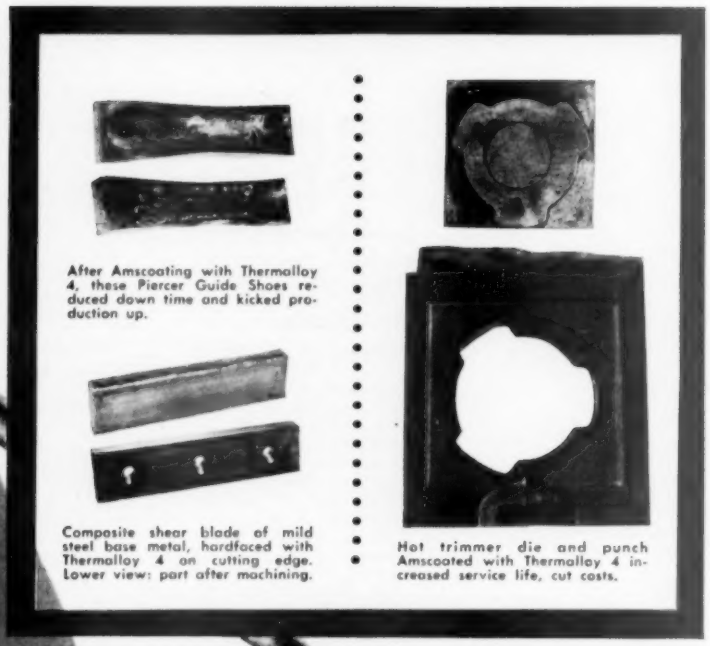

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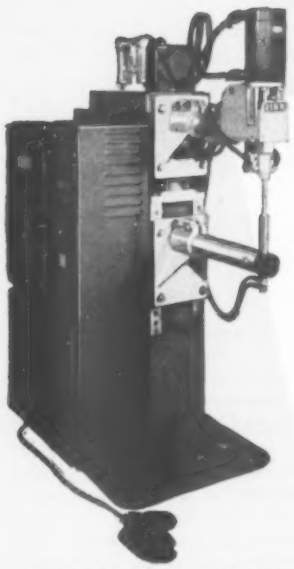

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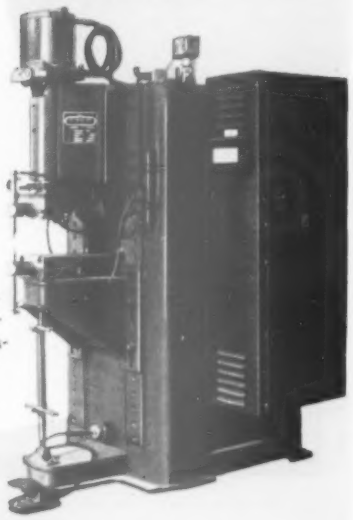

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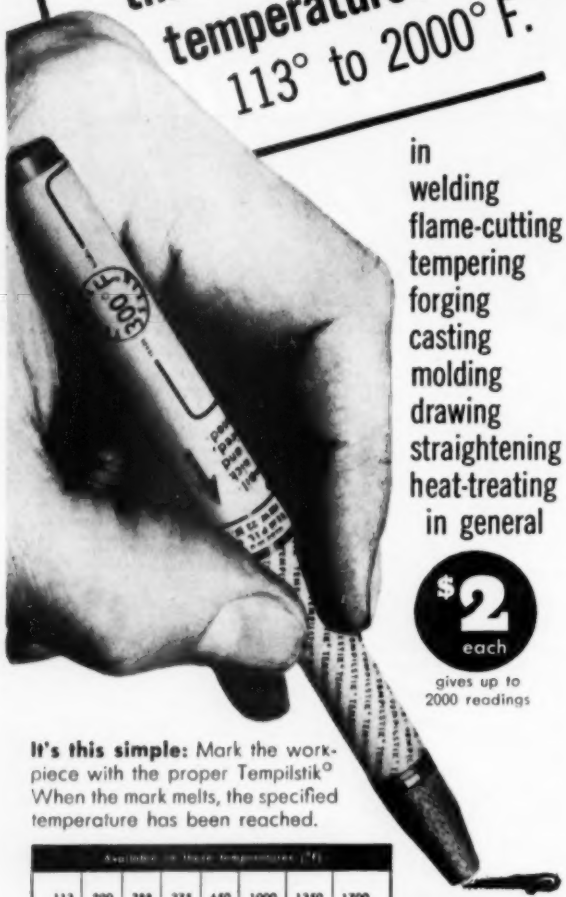

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Supplement to the Welding Journal, June 1953

Controlled Thermal Severity Cracking Test Simulates Practical Welded Joints

An Abstract of work previously published which dealt with the correlation of weldability tests with structural joints and led to the development of the C.T.S. test for hard-zone cracking in alloy steel

by C. L. M. Cottrell

Synopsis

This paper describes briefly the main features of an investigation carried out by the British Welding Research Assn. to produce a simple test for hard-zone cracking in arc-welded low-alloy steel. Experiments were made with restrained fillets,[1] unrestrained fillets,[2] structural joints[2,3] and the CTS (Controlled Thermal Severity) test[4] and the results of this work have been fully reported elsewhere.

Various tests were examined and compared with structural joints, rate of cooling in the hard zone being used as a basis for comparison. The results indicated a relationship, when using a given steel and electrode, between rate of cooling at 300° C in the hard zone and incidence of hard-zone cracking. A weldability test was devised having known grades of thermal severity covering the range obtained in structural joints.

This new weldability test, the CTS test, was used to derive an empirical equation which relates rate of cooling in the hard zone to fillet size (single run) and geometry of the welded joint. A weldability index is proposed, based on the CTS test, for classifying low-alloy steels according to their liability to hard-zone cracking, taking into account the type of electrode used.

INTRODUCTION

THE investigation[1–4] was undertaken to determine the conditions for making sound welds in structures fabricated from a low-alloy manganese-molybdenum steel having a yield strength (0.3% proof stress) of 27 tons per square inch.

C. L. M. Cottrell is Assistant Chief Metallurgist (ferrous) with the British Welding Research Assn., London, England.

The most common type of welded-joint failure in alloy steels is the formation of cracks in the hardened zone of the plate immediately adjacent to the fusion line. It has been suggested by Hopkin[5] that hydrogen which is dissolved in the weld metal is a contributory cause of hard-zone cracking. The relative effects of joint rigidity and rate of cooling on the initiation of hard-zone cracking have not, up to the present, been fully understood. The most satisfactory weldability test in use at the start of the investigation incorporated maximum restraint combined with high rates of cooling. This test is known as the Reeve[6] fillet weld cracking test. The inability to differentiate between effects of the two factors, joint rigidity and cooling rate has been a serious difficulty in attempting to simplify the Reeve test. Until recently the general view has been that it would be safer to retain test conditions more severe than those found in practice, rather than to accept a test that would classify as weldable a steel which might be difficult to fabricate.

Various tests have been examined with the object of devising a simple and reliable weldability test giving equivalent conditions of severity to those in a given structural joint.

MATERIALS

The alloy steel used in this investigation was a low-carbon manganese-molybdenum steel supplied in the

form of plates, bars and sections. The plates for the weldability tests were cut roughly to size and then normalized by heating at 900° C for up to 1 hr, depending on the plate thickness, followed by cooling in air. The plates were then finally machined to the correct dimensions for each test and one surface of each plate was surface ground. In some cases, mild steel was used for the bottom plates in order to conserve alloy material. The mild steel was used in the as-rolled condition and was ground on the top surface.

The bars and sections which were used to fabricate a structure were welded in the as-rolled condition.

The analysis of the alloy steel used is given in Table 1, which indicates the range of composition.

Table 1—Analysis of Mn-Mo Steel Used in Tests

C, %	0.16/0.19
Si, %	0.08/0.23
S, %	0.016/0.044
P, %	0.015/0.037
Mn, %	1.22/1.34
Ni, %	0.33/0.55
Cr, %	0.07/0.20
Mo, %	0.24/0.28

Table 2—Electrodes Used in the Tests

BS 1719 (1951) classification	*Coating*	*Core material*
E111P	Cellulosic	Mild steel
E217	Rutile	Mild steel
E317	Rutile-basic	Mild steel
R456	Oxide-silicate	Mild steel
E537	Oxidizing	Mild steel
E614	Low-hydrogen, basic	Mild steel
....	Rutile	Austenitic 18-8

For the tests on electrodes, one was chosen from each of the BS 1719 electrode classification coating groups 1 to 6, together with an austenitic 18-8 electrode. The classification of the electrodes used is given in Table 2. Most of the other tests were made using the class E217 rutile coated electrode. All welds were made with alternating current, using 125, 170, 210 and 300 amp approximately for 10, 8, 6 and 4 SWG electrodes, respectively.

RESTRAINED WELDABILITY TESTS[1]

Reeve Test

The Reeve test used was that described by Dearden and O'Neill[7] to incorporate two test welds instead of one. The test consisted of two plates of the steel under test bolted to a $2^1/_4$-in. thick mild steel base plate. The top plate was 6 in. square and the bottom plate 12 by 7 in., both plates being of 1-in. thick material. The contact surfaces between all the plates were surface ground in order to ensure good thermal contact, to give uniform heat flow conditions in all tests.

Anchor welds, consisting of three runs, were made on two opposite sides of the top plate. The plates were then allowed to cool to room temperature, before deposition of the test welds in the downhand position.

Miniature Reeve Test

The miniature Reeve test consisted of two plates of the steel under test bolted together with a single $^1/_2$-in. diam bolt. The top plate was 3 by $1^3/_4$ in. and the bottom plate 4 by $3^1/_4$ in., both plates being of the same thickness, namely, $^1/_4$, $^1/_2$ and 1 in. depending upon the thickness of plate tested. The lower surface of the top plate and the upper surface of the bottom plate were surface ground, to ensure uniform heat flow conditions in all tests.

Anchor welds were made round three edges of the top plate. The plates were then allowed to cool to room temperature before deposition of the test weld, in the downhand position, along the third side of the top plate.

Modification 1 of the Miniature Reeve Test

The first modification of the miniature Reeve test was made by bolting a flat mild steel bar 4 ft. by 3 in. by $^1/_2$ in. to the underside of the standard test assembly. A 4-in. length at the center of the upper surface of the bar was surface ground to make good thermal contact with the bottom plate. This modification ensured that an adequate heat sink was available, and also that heat flow to this sink was restricted by the section of the bar which was made similar to that of the test plates. This restriction of heat flow was thought to be necessary in order to simulate conditions occurring in a structure. Only $^1/_2$-in. thick Mn-Mo steel plate was used for these tests.

Modification 2 of the Miniature Reeve Test

When experiments were made on the first modification of the minature Reeve test it was found that bowing upward of the edges of the bottom plate during welding impaired the thermal contact between the bottom plate and the long bar. In the second modification this bowing of the bar was prevented by four $^1/_2$-in. diam bolts. These bolts passed through clearance holes in the bar and were screwed into tapped holes in the bottom plate. The proportions of the heat sink were reduced in this instance, since it was found that the bar used in modification 1 was unnecessarily long. The dimensions of the bar in this case were 12 by 4 by $^1/_2$ in. A 4-in. length at the center was surface ground to ensure good thermal contact with the bottom plate; $^1/_2$-in. thick Mn-Mo steel was again used for the test plates.

Determination of Cooling Rates

Measurements of temperature changes were made on every test weld using a chromel-alumel thermocouple inserted into the plates under test. The hot junction of the thermocouple was placed in the heat-affected zone midway along the horizontal leg of the fillet weld and near the fusion line of the weld bead. The distance

of the thermocouple from the upper surface of the bottom plate, and from the root of the weld was determined by measurements made on microsections cut from previous experimental fillet welds.

Temperatures were measured and recorded on a strip-chart recorder.

Examination of Test Welds

All tests were left for a week before sectioning. The sections were then micropolished, etched in a solution of 3% picric acid with 3% hydrochloric acid in alcohol and examined microscopically for cracks. Crack lengths were measured and reported as a percentage of the total leg length. Hardness surveys were made on the center section from each test weld with a diamond pyramid indenter and 10-kg. load.

Results of Restrained Tests

Tests on 1-in. thick plate showed that the Reeve test was more severe than the miniature test as estimated by the extent of hard-zone cracking, this effect being shown in Table 3. On plates less than 1 in. thick this effect would be greatly accentuated.

Table 3—Results from Restrained Weld Tests (Class E217 Electrodes)

Test assembly	*Plate thickness, in.*	*Fillet size leg length, in.*	*Avg. peak hardness in hard zone, DPN*	*Hard-zone cracking, % of leg length*
Reeve	1	13/32*	396	24
Miniature Reeve	1	13/32*	387	8
	1	7/16	365	Borderline
	1/2	1/4*	419	7
	1/2	5/16†	393	Nil
	1/4	5/32	408	9
	1/4	5/16†	374	Nil
Miniature Reeve (Mod. 1)	1/2	5/16*	394	14
	1/2	7/16	323	Nil
Miniature Reeve (Mod. 2)	1/2	5/16	397	19

* Test welds were also made with smaller fillet sizes and gave more severe hard-zone cracking.

† Test welds were also made with larger fillet sizes and gave no hard-zone cracking.

When these results were obtained it appeared that, whereas the miniature Reeve test probably did not give conditions as severe as those obtaining in practice, the Reeve test represented the maximum possible severity. It was agreed that the restraint in the Reeve assembly was likely to be greater than that present in the miniature test, but at the same time the cooling conditions were markedly different at lower temperatures. This difference in rate of cooling is seen by comparing Figs. 1 and 2, in which the square root of the rate of cooling in the hard zone is plotted against the temperature in that zone for the Reeve and miniature Reeve tests, respectively, on 1-in. thick plates. It was apparent from the negligible differences in average peak hardness values for the two types of test, as given in Table 3, that their rates of cooling at temperatures above 500° C were not very different for a given fillet size, since it is the cooling

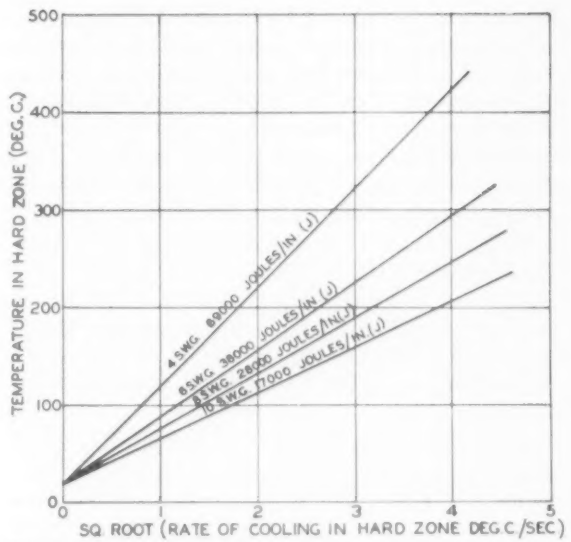

Fig. 1 Square-root cooling-rate curves, Reeve test on 1-in. thick plates. Electrodes class E217

rate at these higher temperatures which controls the degree of hardening of the steel. This fact is also indicated by the form of the square-root rate of cooling curves shown in Figs. 1 and 2.

It is interesting to note that the square-root cooling-rate curves for the Reeve test are in fair agreement with an equation derived by Rosenthal[8] for heat flow in welds. Rosenthal considered only the case for a weld with an "infinite" heat sink and assumed a quasi-stationary state around the welding arc.

The Rosenthal equation indicates that for a given infinite plate the square root of the rate of cooling at a point should be proportional to the temperature of the point. This theoretical consideration is supported by

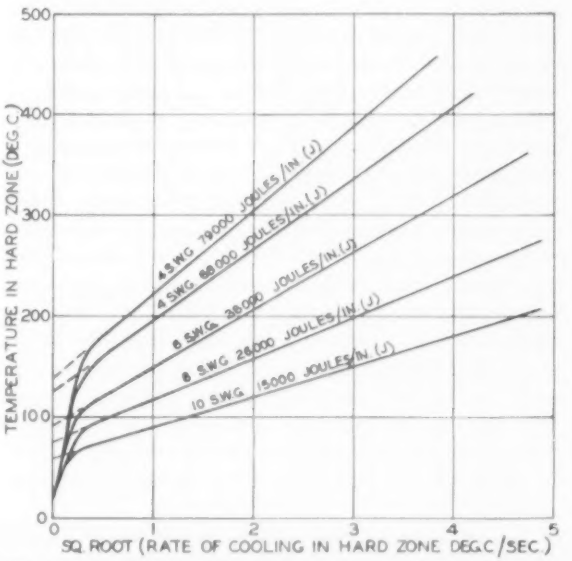

Fig. 2 Square-root cooling-rate curves, miniature Reeve test on 1-in. thick plates. Electrodes class E217

the results of tests with the full Reeve assembly given in Fig. 1. In this figure the square-root rate of cooling curves are in fact straight lines which intersect the temperature axis at the initial plate temperature (20° C).

It will be observed from Fig. 1 that the slope of the curves becomes greater as the energy input value is increased. The slope of these curves from theoretical consideration should be proportional to the heat input, which is nearly true in this case.

These results indicate that the full Reeve test gives a good approximation to an infinite heat sink where metal-arc welding is concerned, and for this reason the test should give thermal conditions as severe as any which may be found in practice.

The results obtained from the miniature Reeve test show that, unlike the Reeve test, it does not act as an infinite heat sink. This is quite understandable from the size relationship of the two tests. The difference between the two tests from the standpoint of cooling rate at various temperatures can be observed from a comparison of Figs. 1 and 2.

It will be observed from Fig. 2 that the general slope of the square-root cooling-rate curves for the miniature Reeve test is less than that obtained for the full Reeve test. This difference in slope is due to the restricted heat flow in the miniature test. The heat energy transferred to the assembly during the welding process is sufficient to raise considerably the temperature of the whole assembly. This complete heat saturation of the test assembly is reflected in the square-root cooling-rate curves and is indicated by the transition from the general slope to a much steeper slope. The steeper slope indicates cooling of the test assembly as a whole, mainly by convection, and obeys a fourth-root relationship with temperature.

The rise in temperature of the miniature Reeve test assembly is more pronounced with thinner plates as shown by a comparison of Fig. 2 with Fig. 3, where the deviation from linearity of the square-root cooling-rate curves can be observed.

In order to provide further evidence of the temperature rise of the miniature Reeve assemblies, the temperature at the edge of the bottom plate remote from the test weld was measured in a number of the tests. These temperatures were measured at intervals and are shown plotted against the temperature in the hard zone in Fig. 4. The curves have been extrapolated to meet the ideal cooling curve where the whole assembly cools as a single mass. The point of intersection of the curves gives the average temperature rise of the assembly in each test. These values for temperature rise, 77 and 96° C, are in fair agreement with those observed from the square-root cooling-rate curves produced to cut the temperature axis, shown in Fig. 3, namely 86 and 102° C.

The background temperature curves are of further use since they show when the restricted size of heat sink is liable to effect the cooling rate in the hard zone.

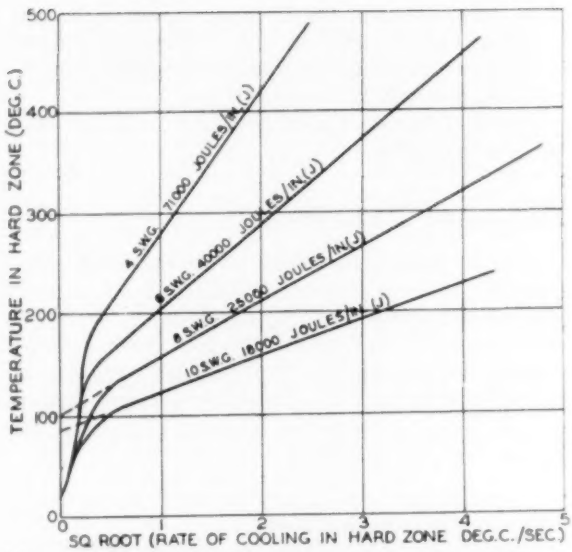

Fig. 3 Square-root cooling-rate curves, miniature Reeve test on $^1/_2$-in. thick plates. Electrodes class E217

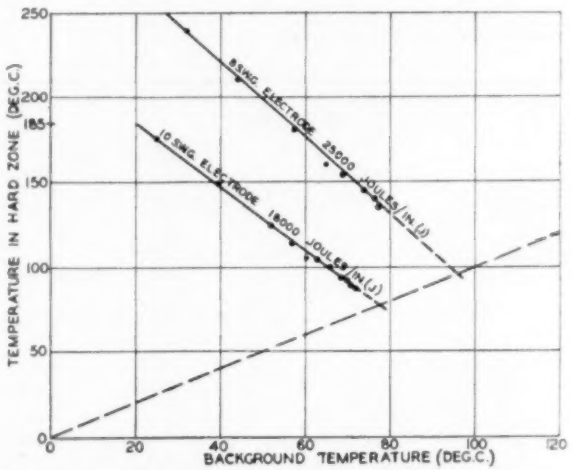

Fig. 4 Determination of temperature rise for miniature Reeve test assembly on $^1/_2$-in. plates. Electrodes class E217

Thus, the temperature of the hard zone at which the background temperature begins to rise gives an indication of the temperature below which the rate of cooling in the hard zone is liable to be affected. These values are 185 and 265° C for the welds made with 10 and 8 SWG electrodes, respectively.

As a result of these experiments it was decided to investigate the possibility of increasing the thermal severity of the miniature Reeve test by increasing the available heat sink, this being done in an effort to bring the test into line with conditions occurring in an actual structure.

The modifications of the miniature Reeve test both gave increased cooling rates when compared with the unmodified test. The square-root cooling-rate curves for tests using both modifications on $^1/_2$-in. thick plates

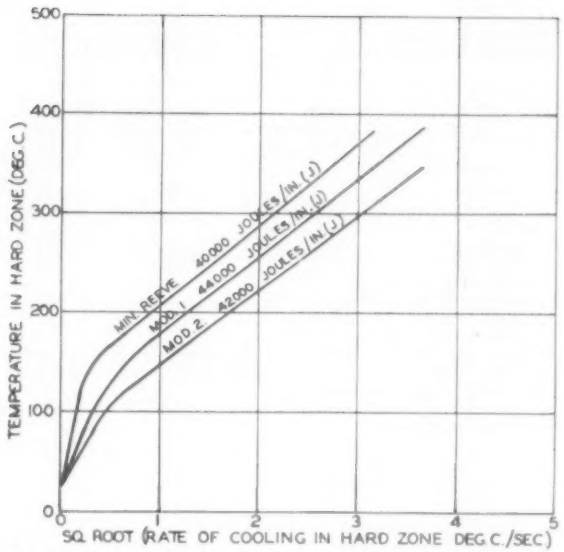
TEMPERATURE IN HARD ZONE (DEG C.)
SQ. ROOT (RATE OF COOLING IN HARD ZONE DEG C./SEC)
MIN. REEVE 40000 JOULES/IN. (J)
MOD. 1 44000 JOULES/IN. (J)
MOD. 2 42000 JOULES/IN. (J)

Fig. 5 Square-root cooling-rate curves for modifications of miniature Reeve test on $\frac{1}{2}$-in. thick plates. Electrodes 6 SWG class E217

are given in Fig. 5, and it will be observed that these approach straight lines more nearly than the curve for the unmodified test. In general the cooling rates for the modified tests were much higher at all temperatures than those for the unmodified tests.

The incidence of hard-zone cracking and the degree of hardening in the heat-affected zone for the tests are given in Table 3. Although the tests carried out on modification 1 of the miniature Reeve test gave higher cooling rates and greater amounts of hard-zone cracking than the unmodified test, the new assembly was not satisfactory due to bowing upward of the edges of the bottom plate.

The test made on modification 2 of the miniature Reeve test showed that although a much smaller bar was used, higher cooling rates were obtained and the amount of hard-zone cracking was increased compared with tests on modification 1. In spite of a considerable increase in hard-zone cracking compared with the standard test, there was no corresponding increase in hardening in the heat-affected zone.

Summary of Restrained Tests

The results have indicated that it was possible to obtain weldability tests with thermal severities lying between those obtained with the full and miniature Reeve tests. The modification of the miniature Reeve test showed that a steel bar could not be fitted to the miniature Reeve test to give satisfactory thermal contact with the bottom plate unless a very special clamping method was used. This method of clamping by means of four extra bolts is considered to be too complicated from the point of view of a practical test.

The relative effects of external restraint, rate of cooling and heat-affected-zone hardness on hard-zone cracking remain to be elucidated, although some interesting results have been obtained relating to rate of cooling and developed hardness in the hard zone. It has been observed in the experiments with the miniature Reeve test and its various modifications that there was very little difference between tests from the standpoint of developed hardness in the hard zone. This indicates that rates of cooling at the higher temperatures are substantially the same. However, low-temperature (less than 400° C) cooling rates and the susceptibility to hard-zone cracking were both markedly increased in the modified tests, from which it can be inferred that the cooling rate at low temperatures has a greater effect on hard-zone crack initiation than the rate at high temperatures.

UNRESTRAINED WELDABILITY TESTS[2]

Unrestrained Fillet Water-Bath Test

In this test, water was used as a means of extending the effective heat-sink of small plates. A fillet weld was made between two 1-in. thick plates of the Mn-Mo steel. The two plates were supported at an angle of 45 deg to the horizontal in a tank which was partially filled with water. The volume of water in the tank was 2500 ml and the surface of the water was approximately $1\frac{1}{2}$ in. below the root of the fillet weld. The bottom plate projected 1 in. beyond the edge of the top plate and the test fillet weld was made in the downhand position. The water was at room temperature immediately before welding.

Unrestrained Fillet Test

This test consisted of a fillet weld made between a top and bottom plate of $\frac{1}{4}$-in. thick Mn-Mo steel. The dimensions of the top and bottom plates were 6 by 4 in. and 12 by 4 in., respectively. These lengths of plate were chosen in order to obtain a sufficiently large heat-sink to avoid heat saturation during welding. At the same time heat flow away from the weld was restricted by the small plate thickness.

Two different degrees of thermal severity were obtained with the unrestrained fillet test. The less severe test weld (bithermal)* was made at the end of both plates. The more severe test weld with trithermal severity was made between the end of the top plate and the middle of the bottom plate. The test weld length in the bithermal test was 3 in., but in the trithermal test, weld lengths of 4, 3 and 2 in. were used. These variations of weld length were made to study the effect of "weld length/plate width" ratio on cooling rate and hard-zone cracking. In all instances the mid-point of the weld coincided with the centre-line of the plates.

* A test with bithermal severity is one in which heat can flow away from the weld through two plate sections; similarly in a test with trithermal severity heat can flow through three plate sections.

Test Details

The direct cooling curves were obtained by using a photographic recording apparatus. The apparatus consisted of a fast response (0.3 sec) temperature indicator calibrated to read in centigrade degrees, a $^1/_{20}$ second stop watch and an arc-voltage indicator, all three instruments being photographed continuously on 16-mm film during and after welding.

The same procedure was used for the examination of test welds as that described previously.

Results of Unrestrained Tests

The tests using the unrestrained fillet water-bath assembly with 1-in. thick steel all showed cracking in the hard zone. This result is important since it was previously thought that external restraint was the major factor in the formation of hard-zone cracks. The results are indicated in Table 4. The cracking was quite severe with the weld of smallest fillet size and less severe with the largest weld. This result is to be expected if rate of cooling in the hard zone is a major factor in the formation of hard-zone cracks. Another interesting feature was the presence of cracking with an average peak hardness value in the hard zone of only 382 DPN, since joint rigidity cannot have been the reason for cracking occurring at this relatively low hardness. The square-root cooling-rate curves for the water-bath tests deviated only slightly from straight lines, indicating that the water bath provided a sufficient heat-sink to avoid heat saturation of the test plates.

The results obtained with the unrestrained fillet test on $^1/_4$-in. thick steel showed that, as with the water-bath test, hard-zone cracks could be obtained in unrestrained fillet welds.

The effect of test-weld length on hard-zone crack formation and cooling rate was studied. Decreasing the test-weld length from 4 to 3 in. yielded both an increase in hard-zone cracking and in cooling rate. However, decreasing the test-weld length from 3 to 2 in. did not produce such a marked change. The remainder of the tests were therefore made using a 3-in. long test weld.

Test welds made on the unrestrained fillet assembly with variations in joint geometry gave some interesting results. The trithermal test assembly proved more severe than the bithermal test assembly both from the point of view of hard-zone cracking and rate of cooling. The difference in cooling rate for the two test assemblies is shown in Fig. 6. The difference between cooling rates for similar welds on the two assemblies shows the difference in heat flow between butt welds and fillet welds as represented by the bithermal and trithermal tests, respectively.

Table 4—Results from Unrestrained Weld Tests (Class E217 Electrodes)

Test assembly	*Plate thickness, in.*	*Fillet size leg length, in.*	*Avg. peak hardness in hard zone, DPN*	*Hard-zone cracking, % of leg length*
Unrestrained Fillet water bath	1	$^{13}/_{32}$*	382	9
Unrestrained Fillet (trithermal)	$^1/_4$	$^3/_{16}$	415	12
	$^1/_4$	$^1/_4$	380	Nil
Unrestrained Fillet (bithermal)	$^1/_4$	$^3/_{16}$†	358	Nil

* Test welds were also made with smaller fillet sizes and gave more severe hard-zone cracking.

† A test weld was also made with a larger fillet size and gave no hard-zone cracking.

The effect of joint geometry on hard-zone cracking is shown in Table 4 where results are given for bithermal and trithermal tests on $^1/_4$-in. thick plate. Table 4 also gives hardness values for the hard zone of both bithermal and trithermal tests, the hardness being greater with the trithermal test.

Test welds were also made with the trithermal unrestrained fillet-weld assembly on the steel in different conditions. The plates were as-rolled, normalized, and normalized with subsequent machining, giving three different surfaces on which test welds were made. There was some indication that the unmachined normalized plate gave the best weldability, although the tests were not exactly comparable, owing to small variations in heat input. It is possible that large amounts of

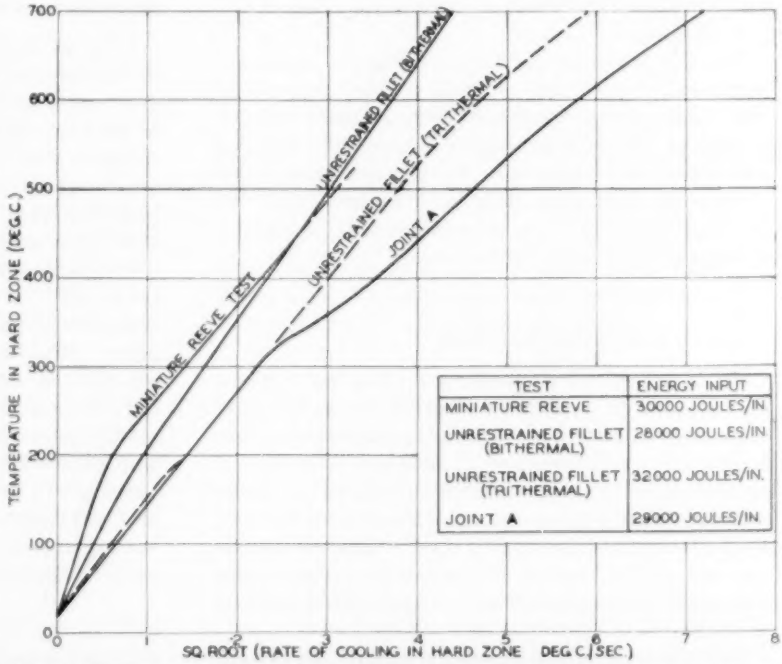

Fig. 6 Square-root cooling-rate curves for various weldability tests and structural joint A, $^1/_4$-in. steel. Electrodes 8 SWG class E217

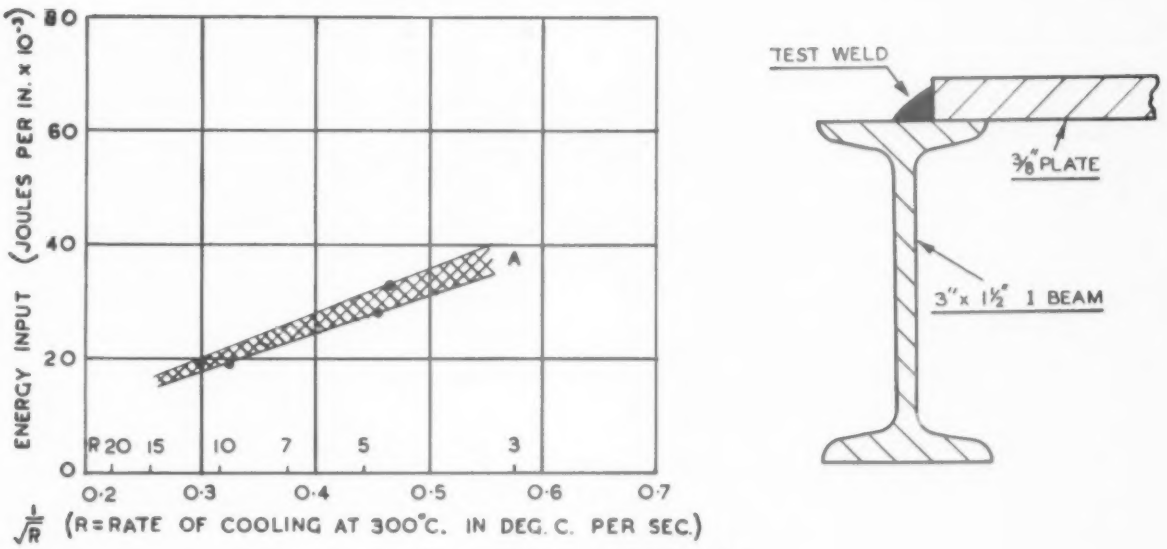

Fig. 7 Thermal severity of joint A

iron oxide in the weld pool, due to the relatively thick normalizing scale, may have affected the oxygen/hydrogen equilibrium. If so, then the reduction of potential hydrogen would tend to lessen the severity of hard-zone cracking.

Normalizing treatment alone did not appear to affect weldability. Normalizing the steel effected a reduction in initial plate hardness, but did not result in a corresponding reduction in hardness in the heat-affected zone.

The cracks found in the unrestrained fillet tests were visible only at magnifications of over 100 diameters and have been termed microcracks.

TESTS ON STRUCTURAL JOINTS[3]

Test Details

The structural tests consisted of welds made on Mn-Mo steel channel section, I-section and plate of various thicknesses. The joints tested, with their code letters and dimensions, are shown in cross section in Figs. 7, 8, 9 and 10.

The method of determining cooling curves was similar to that used for the unrestrained fillet tests.

The joints were incorporated in a rigid structure to ensure the presence of external restraint.

Results of Structural Tests

The form of the square-root cooling-rate curves for the various joints tested was modified by the heat-sink

Table 5—Results from Tests on Structural Joints (Class E217 Electrode)

Joint code letter	*Section thickness in.*	*Fillet size leg length, in.*	*Avg. peak hardness in hard zone DPN*	*Hard-zone cracking, % of leg length*
A	1/4–3/8	5/16	403	3.7
		1/4*	355	Nil
B	1/4–1 1/2	5/16†	391	20
		3/8	332	Nil
C	1/4–3	1/4 × 1/2	377	1.6
		1/4 × 5/8	309	Nil
M	1/4–1	5/16	395	1.6
		3/8	325	Nil

* Test welds were also made with larger fillet sizes and gave no hard-zone cracking.

† Test welds were also made with smaller fillet sizes and gave hard-zone cracking.

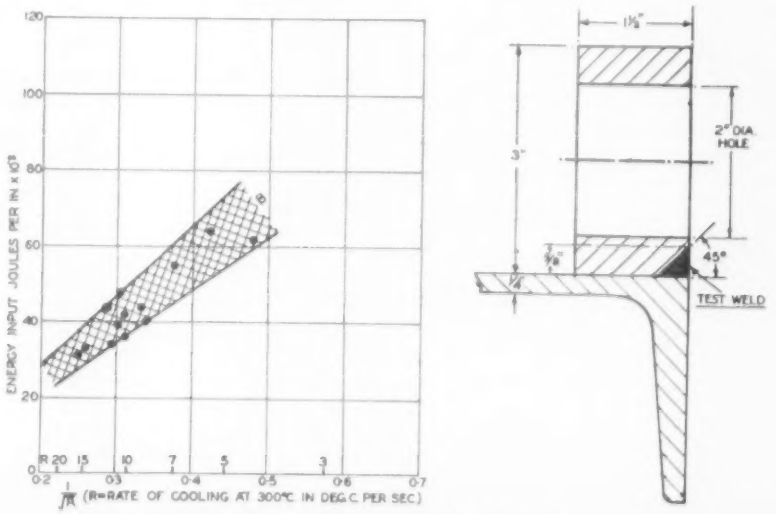

Fig. 8 Thermal severity of joint B

saturation and by other effects. Curves for joints *A* and *B* showed changes of slope at various temperatures. In cooling through the temperature range 400–300° C, the slopes of the curves for joint *A* became less steep, this change coinciding with the heat saturation of the top flange of the I-beam. A similar effect was shown in joint *B*, though this occurred at a lower temperature (300–200° C) and was probably due to the effect of the hole in the $1^1/_2$-in. thick bar.

The results of the tests on structural joints are given in Table 5 and values for hardness developed in the hard zone are also shown for comparison.

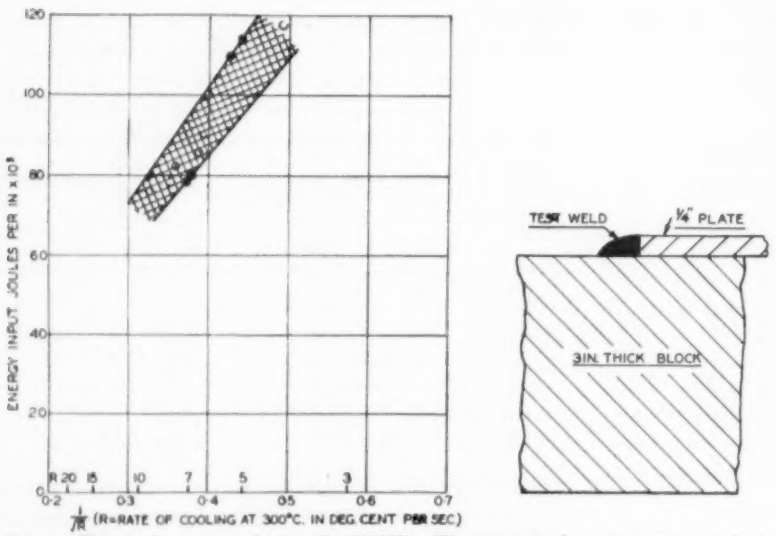

Fig. 9 Thermal severity of joint C. **NOTE:** *The open circles represent two similar welds made on a 6-in. thick block*

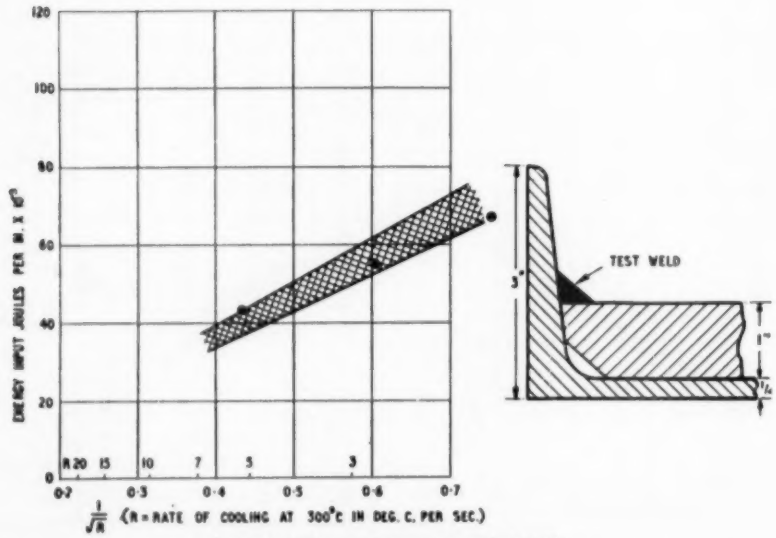

Fig. 10 Thermal severity of joint M

SUMMARY OF RESULTS WITH RESTRAINED, UNRESTRAINED AND STRUCTURAL TESTS

Correlation of Cooling Rates and Hard-Zone Cracking

Since it appeared that rate of cooling in the hard zone was an important factor in the initiation of hard-zone cracks, it was decided to investigate the effect of rate of cooling at various temperatures on hard-zone crack formation.

In order to relate cooling rate at various temperatures in the heat-affected zone with cracking in that zone, it was necessary to observe two cooling-rate curves in each test. One curve was from a test in which slight cracking had occurred, the other from a test with slightly lower cooling rate, but in which no cracking had occurred. The area formed between these two curves indicated a borderline region of weldability. Several pairs of curves, taken from various weldability tests and structural joints, were plotted together, and the area of doubtful weldability was thus limited to a given range of temperature.

Several pairs of these curves for tests with E217 rutile-coated electrodes on the alloy steel are shown in Fig. 11, and the area of doubtful weldability is shown hatched. Although the external restraint imposed on these test welds varied from severe to no restraint, there is a range of temperature over which rate of cooling in the hard zone appears to have a major influence in the initiation of hard-zone cracks. This range of temperature extends from about 200 to 400° C.

It is considered that there is some theoretical basis for the importance of the temperature range 200–400° C since it represents cooling during the transformation of the heat-affected zone from austenite to martensite. It is known that the plate material immediately adjacent to the fusion line becomes charged with hydrogen from the weld metal. This hydrogen will probably be forced into the plate material during the depressed transformation (600° C approximately) of the weld metal, when there is a sudden drop in the solubility of hydrogen. The plate material becomes charged with hydrogen in this manner (while it is still in the austenitic state), then as the metal transforms at lower temperatures (300–400° C) the hydrogen

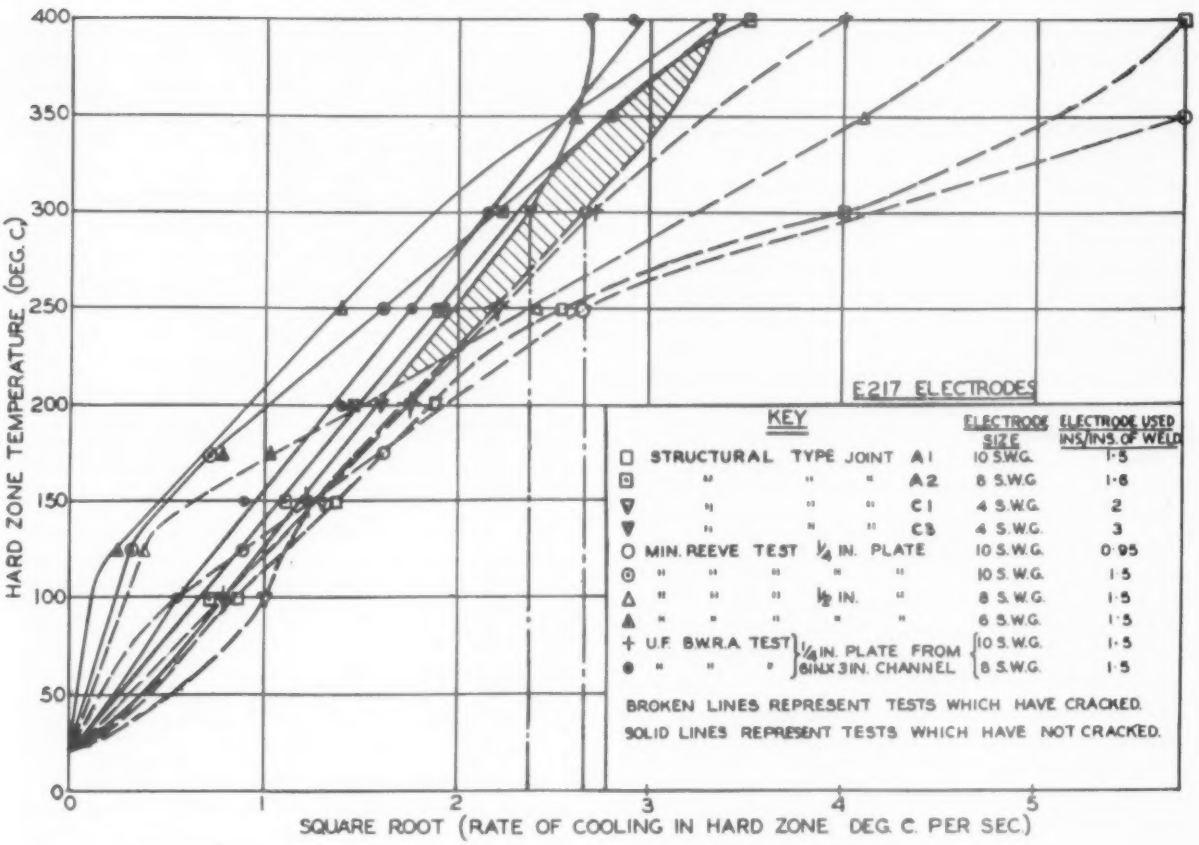
HARD ZONE TEMPERATURE (DEG. C.)
SQUARE ROOT (RATE OF COOLING IN HARD ZONE DEG. C. PER SEC.)
E217 ELECTRODES
KEY
ELECTRODE SIZE
ELECTRODE USED INS./INS. OF WELD
STRUCTURAL TYPE JOINT A1 10 S.W.G. 1·5
" " " A2 8 S.W.G. 1·6
" " " C1 4 S.W.G. 2
" " " C3 4 S.W.G. 3
MIN. REEVE TEST ¼ IN. PLATE 10 S.W.G. 0·95
" " " " " 10 S.W.G. 1·5
" " " ½ IN. " 8 S.W.G. 1·5
" " " " " 6 S.W.G. 1·5
U.F. B.W.R.A. TEST ¼ IN. PLATE FROM 6 IN. X 3 IN. CHANNEL 10 S.W.G. 1·5
" " " 8 S.W.G. 1·5
BROKEN LINES REPRESENT TESTS WHICH HAVE CRACKED.
SOLID LINES REPRESENT TESTS WHICH HAVE NOT CRACKED.

Fig. 11 Comparison of square-root cooling-rate curves for slightly cracked and uncracked joints

will be thrown out of solution. It is possible that the release of hydrogen in the martensite at this stage leads to the production of stress centers, which may account for the importance of cooling rate over this temperature range.

The rate of cooling at high temperatures (400–900° C) decides the transformation products to be found in the heat-affected zone, whereas the rate of cooling at low temperatures (room temperature to 200° C) probably controls the progress of delayed transformation (i.e., decomposition of retained austenite). This delayed transformation is also associated with the liberation of hydrogen and the initiation of hard-zone cracks. It is thought likely that, provided a certain rate of cooling at high temperatures (400–900° C) is obtained in the hard zone, the rate of cooling in the region of 300° C is the main factor in the initiation of hard-zone cracks for a given electrode/plate combination. The particular cooling rate at high temperatures might well be that required to produce a small amount of martensite. Under most welding conditions with the Mn-Mo steel this rate is exceeded and the rate of cooling at 300° C becomes the operative factor. The square-root cooling-rate curve for joint *C* (Fig. 11) gives a good indication of the way a comparatively low cooling rate at high temperatures, combined with a rate at 300° C higher than the critical rate, promotes hard-zone cracking.

In the results given in Fig. 12 the rate of cooling at 300° C is related to the presence or absence of hard-zone cracking in the Mn-Mo steel, welded with class E217 electrodes. When the rate of cooling at 300° C did not exceed 6 centigrade degrees per second, the steel was welded without hard-zone cracks irrespective of whether the weld was fully restrained, partly restrained or unrestrained.

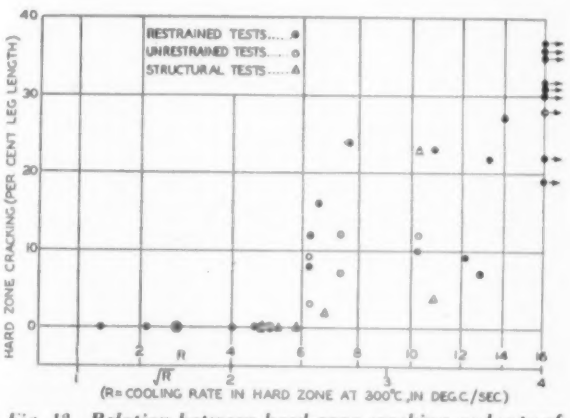
RESTRAINED TESTS..... ●
UNRESTRAINED TESTS..... ○
STRUCTURAL TESTS..... △
HARD ZONE CRACKING (PER CENT LEG LENGTH)
(R = COOLING RATE IN HARD ZONE AT 300°C. IN DEG.C./SEC.)

Fig. 12 Relation between hard-zone cracking and rate of cooling. Electrode class E217

Correlation Between Cooling Rates Obtained in Weldability Tests and in Structural Joints

As the rate of cooling at 300° C in the hard zone has been shown to be an important factor in the initiation of hard-zone cracks, the comparison between weldability tests and structural joints can be more easily made, since it is only necessary to compare cooling rates at 300° C.

In Fig. 6 the trithermal and bithermal tests on unrestrained fillets are compared with the miniature Reeve test and structural joint *A*. Whereas the trithermal unrestrained fillet test gave a cooling rate at 300° C identical with that of the structural joint, the bithermal unrestrained fillet test and the miniature Reeve test gave much lower cooling rates.

From the previous results it is apparent that trithermal flow is an important feature which should be incorporated in a weldability test, in order that the test may simulate cooling-rate conditions occurring in structural joints. The extension of the miniature Reeve test plates behind the test weld, as in the bithermal unrestrained fillet test, produces some increase in cooling rate at temperatures below 400° C because of the larger heat-sink, as indicated in Fig. 6. The heat flow to the sink is restricted to bithermal flow, and no increase in cooling rate is therefore obtained at high temperatures. If, however, the bottom plate is also extended in front of the test weld, the flow becomes trithermal, with consequent increase in cooling rate at all temperatures. When the plates are extended in this manner, test conditions can be obtained which closely resemble those occurring in structural joints.

In considering the relationship between cooling conditions in joint B and in the weldability tests, it is interesting to note that there was some tendency for the square-root cooling-rate curves to have a "hump" at about 250° C, though this was much less pronounced than in the miniature Reeve test. The cause of this hump was the saturation of the heat-sink.

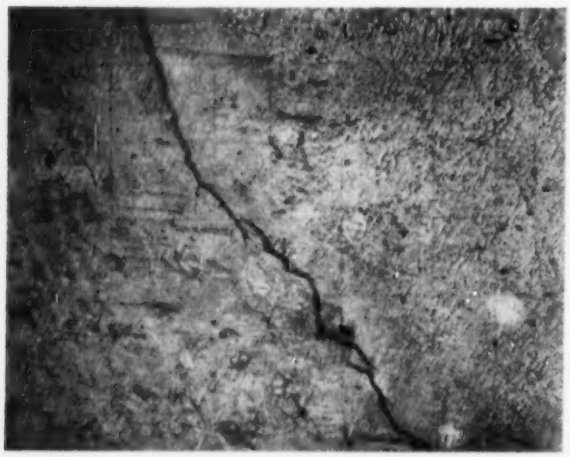

Fig. 13 Microcrack in hard zone of unrestrained fillet test. Etched in 2% nital. × 100

The tests on joint *C* gave cooling conditions similar to those obtained with the full Reeve test on 1-in. plates because this joint had, in effect, an infinite heat-sink. The miniature Reeve test, however, gave square-root cooling-rate curves unlike those of the joints. The ideal test to give conditions of heat flow similar to this joint would be one having trithermal flow with an adequate heat-sink, and using 1- to 2-in. thick plates.

The relationship between energy input* and rate of cooling in the heat-affected zone at 300° C is shown for various joints in the form of Thermal Severity Curves in Figs. 7, 8, 9 and 10. Energy input can be related to fillet size as will be shown later. The value of energy input to each weld was measured by means of an integrating induction-type watt-hour meter.

Discussion of Results

The results have indicated the chief factors to be taken into account in the design of a weldability test giving conditions equivalent to those obtaining in structural joints. At the start of the investigation the relative effects of external restraint and cooling rate on the initiation of hard-zone cracks were not known. It was thought that developed hardness could be related to the formation of hard-zone cracks. Although there was no doubt about the weldability of a steel which would pass the full Reeve test, it was felt that in a number of cases this test was too severe. In addition, the full Reeve test required much preparation and material and a smaller and more simple test was therefore desirable.

The following important points arising from this work are noted below for use in developing a suitable weldability test.

(*a*) External restraint is not necessary to initiate hard-zone cracks, although it assists in enlarging them.

(*b*) For a given electrode/plate-metal combination the rate of cooling at 300° C in the hard zone appears to be a critical factor in the initiation of hard-zone cracks.

(*c*) The total heat-sink of the test assembly must therefore be large enough for the rate of cooling at 300° C not to be affected. The heat-sink of the miniature Reeve test does not satisfy this condition, and bolting more metal to the test assembly was found to be an unsatisfactory method of adding to the heat-sink.

(*d*) Where the test is to give conditions similar to a normal fillet weld it should be designed so as to incorporate conditions of trithermal flow.

Referring to point (*a*), it is desirable for some degree of external restraint to be present in a test, since this restraint tends to widen cracks which occur in the hard zone. This fact is illustrated by a comparison of Fig. 13 with Fig. 14. Figure 13 shows a typical microcrack observed in the unrestrained fillet test and Fig. 14 a large crack found in the heavily restrained full Reeve test. There is also some indication (Fig. 12) that in the fully restrained tests the hard-zone cracks are

* Total arc energy.

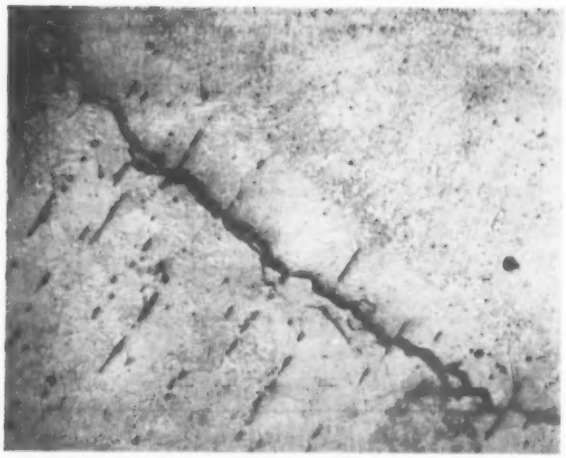

Fig. 14 Crack enlarged due to external restraint in the Reeve test. Etched in 2% nital. × 100

slightly longer than in the unrestrained tests at cooling rates just above the critical value. This indicates that restraint tends to extend small cracks and so makes them more easily seen under the microscope. When higher cooling rates obtain (greater than 15 centigrade degrees per second at 300° C) and cracks are longer, it appears that external restraint has little effect upon the crack length. This external restraint should not be confused with the restraint which is self-imposed by the contraction stresses due to the cooling metal, or with transformation stresses. Such contraction and transformation stresses are present in a simple "bead-on-plate" weld. From these considerations it would appear that some external restraint should be incorporated in the test in order to make the cracks more easily seen.

Point (*b*), which refers to the existence of a critical cooling rate, is concerned with heat flow away from the joint, and is therefore discussed with points (*c*) and (*d*). In considering (*c*), which refers to the size of total heat-sink necessary in weldability tests, the results shown in Fig. 4 are important. These results indicated that in the miniature Reeve test, cooling rates were affected by the small heat-sink as shown in Table 6, which gives an additional result for $^3/_4$-in. thick plates.

It is reasonable to infer from these results that, with fillet sizes (leg lengths) larger than $^1/_4$ and $^5/_{32}$ in., respectively, on $^1/_2$- and $^1/_4$-in. plates, the heat-sink of the miniature Reeve test would be inadequate (i.e., would reduce the rate of cooling at 300° C). So that the fillet size can be increased to equal the plate thickness without reducing the test severity, it would be necessary to enlarge the heat-sink of the test considerably. The volume of the heat-sink for the new test on $^1/_4$-in. thick plates should therefore be made not less than that of the miniature Reeve test on $^1/_2$-in. thick plates (i.e., doubled) where a $^1/_4$-in. fillet (Table 6) was the largest size which could be used without reducing the cooling rate at 300° C. The volume of the heat-sink in the miniature Reeve test is $18^1/_4 t$ cub in., where t is the plate thickness in inches. Therefore the volume of the ideal weldability test assembly should be greater than $36^1/_2 t$ cub in.

With reference to point (*d*) the various conditions of heat flow which can occur in practice should first be considered, and for this reason a few simple examples are shown in Fig. 15. The condition of unithermal* flow is not likely to be found in practice. Bithermal flow occurs in butt welds and trithermal flow in the majority of fillet welds. More severe conditions of heat flow are also shown in Fig. 15 but these two types of flow are not very common. The best compromise for a weldability test is that it should give conditions equivalent to the most common butt and fillet joints, and the conditions necessary to satisfy this requirement are bithermal and trithermal flow. The length of each path available for heat flow is also important and this is linked with the previous discussion on total size of heat-sink, the ideal condition being obtained when all the path lengths are equal to or greater than 3 in.

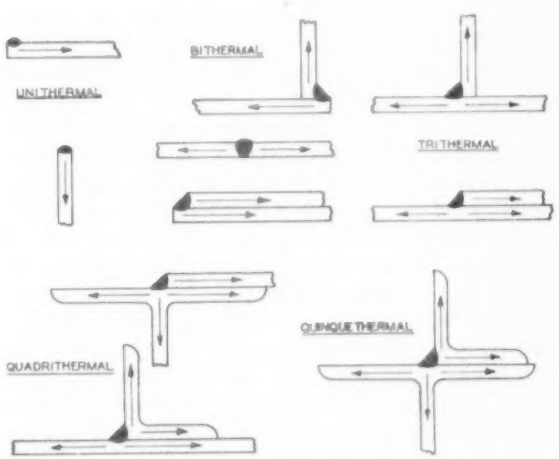

Fig. 15 Heat flow conditions related to joint geometry

Having considered in detail all the relevant points in the design of a weldability test for high-tensile steel, it is now possible to specify the ideal test which, because it is based on heat flow, is termed the CTS (Controlled Thermal Severity) test. Since it is to be a restrained test the most simple form comprises two plates with a single clamping bolt. In order to obtain substantially

Table 6—Temperature Below Which Cooling Rate Is Affected by the Small Heat Sink in the Miniature Reeve Test. Manganese-Molybdenum Steel. Electrodes Class E217

Plate thickness, in.	*Electrode size, SWG*	*Fillet size, in.*	*Energy input, joules/in. × 10⁻²*	*Temperature below which cooling rate will be affected, ° C*
$^1/_2$	10	$^3/_{16}$	18	185
	8	$^1/_4$	25	265
$^1/_4$	10	$^5/_{32}$	11	280

* Heat flow through the equivalent of one plate section.

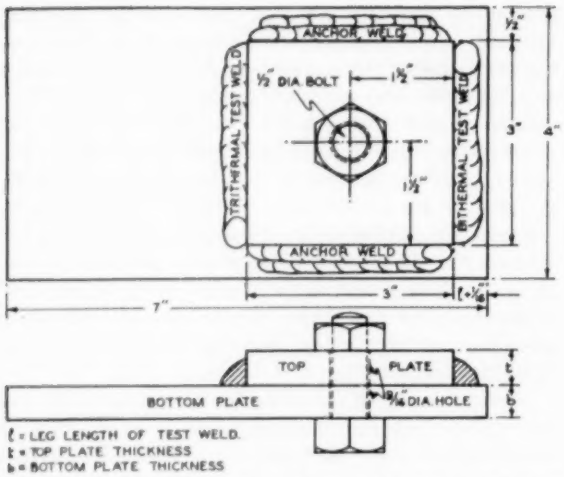

Fig. 16 CTS weldability test assembly for alloy steel

equal path lengths in the trithermal test the bottom plate should be at least twice as long as the top plate and for simplicity the top plate should be square. A 3-in. square top plate on a 4- by 7-in. bottom plate meets these requirements and gives an adequate length of test weld. In addition, the heat-sink volume is $37t$ cub in. which is greater than the minimum requirement of $36\frac{1}{2}t$ cub in. Figure 16 shows how the top plate is placed near to one end of the bottom plate and restraining welds are made along two opposite sides of the top plate. The bithermal test weld is made along the top plate edge adjacent to the end of the bottom plate and the trithermal weld along the opposite edge of the top plate. Both trithermal and bithermal test welds can be made on one assembly provided that it is allowed to cool to room temperature between tests.

EXPERIMENTS WITH THE CTS TEST[1]

Test Procedure

The thermal severity of a welded joint depends upon the combined cross-sectional area of the paths through which heat can flow away from the joint. In the CTS test a thermal severity number of one (TSN 1) is taken to refer to heat flow through one section of $\frac{1}{4}$-in. thick plate, and this is termed unithermal $\frac{1}{4}$-in. flow. Similarly TSN 2 refers to heat flow through two sections of $\frac{1}{4}$-in. plate (bithermal $\frac{1}{4}$ in.) or one section of $\frac{1}{2}$-in. thick plate (unithermal $\frac{1}{2}$ in.). The complete set of CTS test assemblies and their thermal severity numbers are given in Table 7. It will be seen that the tests comprise a main series where top and bottom plates of equal thickness are used, and a supplementary series with $\frac{1}{4}$-in. top plates on $\frac{1}{2}$- and 1-in. thick bottom plates. Plates of other thicknesses could be used, and other combinations of top and bottom plate are possible.* The thermal severity number of a test may be

Table 7—CTS Test Assemblies and Thermal Severity Numbers

Top plate thickness, in.	*Bottom plate thickness, in.*	*Heat flow from test weld*	*Thermal severity number TSN,*
		Main series	
1/4	1/4	Bithermal	2
		Trithermal	3
1/2	1/2	Bithermal	4
		Trithermal	6
1	1	Bithermal	8
		Trithermal	12
2	2	Bithermal	16
		Trithermal	24
		Supplementary Series	
1/4	1/2	Bithermal	3
		Trithermal	5
1/4	1	Bithermal	5
		Trithermal	9

obtained from the following formulas:

$$\text{TSN} = 4(t + b) \text{ for bithermal welds (Fig. 16)}$$
$$\text{TSN} = 4(t + 2b) \text{ for trithermal welds (Fig. 16)}$$

where t is the thickness in inches of the top plate and b is the thickness in inches of the bottom plate.

The dimensions of the test plates and the method of assembly are shown in Fig. 16. The edges of the top plate were machined, and one face of each plate was surface ground, the assembly being bolted together with the two surface-ground faces in contact.

Anchor welds were made on two opposite sides of the top plate as shown in Fig. 16 and the test assembly was allowed to cool to room temperature before making the first test weld.

The first test weld (bithermal) was made in the downhand position. After the assembly had cooled to room temperature the second test weld (trithermal) was made, also in the downhand position. The tests were made with class E317 rutile-basic coated electrodes.

The hot junction of a chromel-alumel thermocouple was inserted in the heat-affected zone of each test weld at the mid-length of the horizontal leg, as described previously. The thermocouple was connected via compensating leads to a fast-response potentiometric recorder, having a maximum response speed of 550 centigrade degrees per second.

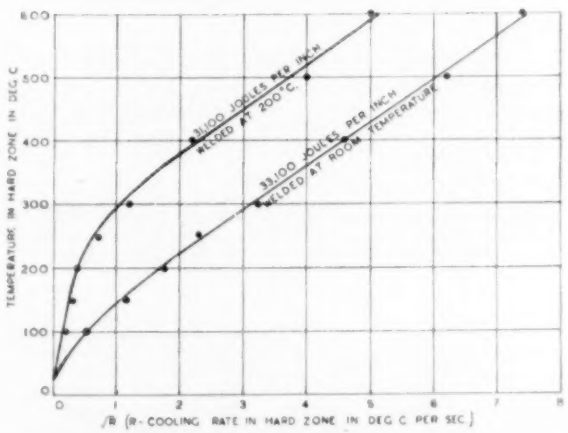

Fig. 17 Effect of preheat on a CTS test

* When one plate is thick and there is a marked difference between the thicknesses of the two plates, the calculated TSN value will indicate more severe thermal conditions than those which actually occur.

The energy input to each weld was measured by means of an integrating induction-type watt-hour meter.

Derivation of Thermal Severity Curves

Rates of cooling at various temperatures were obtained by taking tangents from the direct cooling curves.

In order to relate these cooling rates to the amount of heat supplied to the weld from the arc, their square roots were plotted against the energy input* in joules per inch of weld. A linear relationship has been shown to exist between temperature and the square root of the rate of cooling, for long welds on plate of "infinite" extent, by D. Rosenthal.[3] The departure from linearity of the root-rate curves obtained from CTS tests is explained by the finite dimensions of the test, causing a change in slope of the curves as the plates become heated. A typical root-rate curve for a CTS test is shown in Fig. 17.

It was obvious that a higher rate of cooling could be obtained, either by increasing the plate thickness, or number of paths available for heat flow, or by decreasing the energy input (fillet size). To obtain a measure of the thermal severity of a test, which would indicate the cooling rate obtainable with any weld size, thermal severity curves were plotted. These curves have energy input (fillet size) as ordinate and $1/\sqrt{R}$ a abscissa, where R is the rate of cooling at 300° C in centigrade degrees per second. Two sets of curves have been plotted for the CTS tests, and these are given in Figs. 18 (*a*) and 18 (*b*). Figure 18 (*a*) shows thermal severity curves for trithermal welds using $^1/_4$-, $^1/_2$- and 1-in. thick material, and Fig. 18 (*b*) shows a similar set of curves for the bithermal welds. These curves all conform approximately to the empirical equation:

$$R = \frac{1}{\left(\frac{48 \times E}{N \times 10^6} + 0.05\right)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The rate of cooling at 300° C in any test having a thermal severity number below the limiting value can therefore be derived theoretically where E is the energy input in joules per inch of weld, and N is the thermal severity number. It must be noted that this formula is only applicable to welds made on plates initially at room temperature (i.e., approximately 20° C).

Limiting Cooling Rates for Various Weld Sizes

The tests indicate that there is a maximum limiting cooling rate for any given size of weld fillet. In the

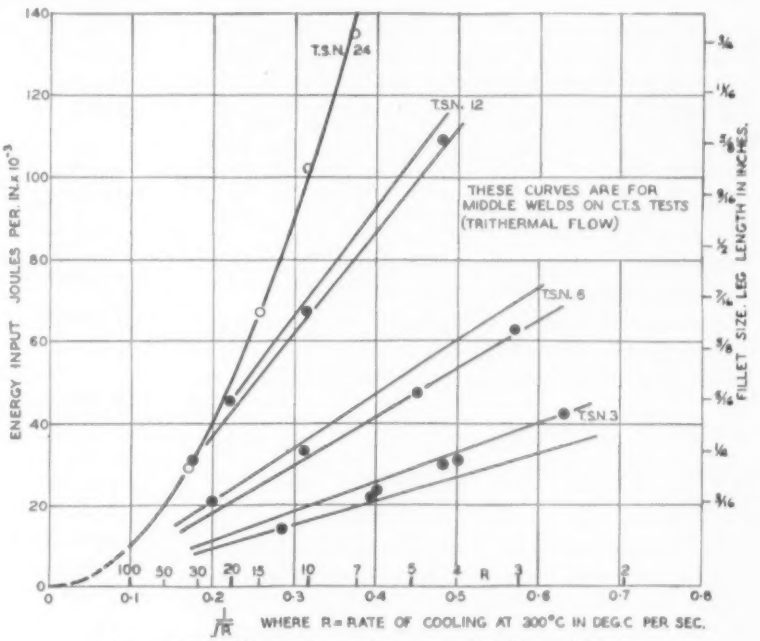
T.S.N. 24
T.S.N. 12
THESE CURVES ARE FOR MIDDLE WELDS ON C.T.S. TESTS (TRITHERMAL FLOW)
T.S.N. 6
T.S.N. 3
ENERGY INPUT JOULES PER IN. x 10⁻³
FILLET SIZE: LEG LENGTH IN INCHES.
WHERE R = RATE OF COOLING AT 300°C IN DEG.C PER SEC.

Fig. 18 (a) Thermal severity curves (trithermal flow)

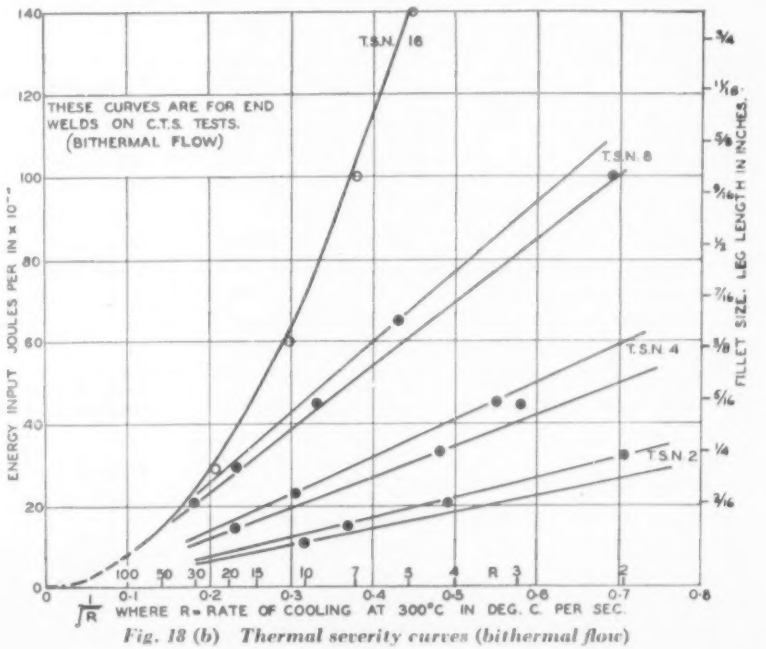
T.S.N. 16
THESE CURVES ARE FOR END WELDS ON C.T.S. TESTS. (BITHERMAL FLOW)
T.S.N. 8
T.S.N. 4
T.S.N. 2
ENERGY INPUT JOULES PER IN x 10⁻³
FILLET SIZE: LEG LENGTH IN INCHES.
WHERE R = RATE OF COOLING AT 300°C IN DEG. C. PER SEC.

Fig. 18 (b) Thermal severity curves (bithermal flow)

* Total arc energy.

case of a fillet weld of $^1/_4$-in. leg length, the maximum cooling rate is obtained when it is laid on 1-in. thick material in the trithermal test (TSN 12), and no higher rate of cooling is obtained when the same fillet size is used in a trithermal test in 2-in. thick material (TSN 24). With larger fillet sizes, a greater severity than TSN 12 is necessary to produce the maximum cooling rate.

A line is drawn on Figs. 18 (*a*) and 18 (*b*) to represent the maximum cooling rate attainable for any given energy input of fillet size. It will be seen that this line is different for bithermal and trithermal welds. This is due to the fact that heat can flow away from a trithermal weld in directions within 270 deg of a circle having having its center on the weld axis, whereas, in a bithermal weld, heat flow is restricted to directions within approximately 180 deg of a circle. The curves for maximum attainable cooling rates are given in Figs. 18 (*a*) and 18 (*b*) and conform to the equation:

$$R = \frac{p}{E} \times 10^6 \ldots\ldots\ldots\ldots (2)$$

For the trithermal tests, p has been taken as unity, and for the bithermal tests as 0.71.

In each case the points obtained for welds on 2-in. thick material lie on the appropriate limiting line. These are shown as open circles in Figs. 18 (*a*) and 18 (*b*).

Relation Between Thermal Severity and Joint Geometry

The thermal severity curves given for the range of CTS tests cover most cases which are likely to be found in practice. Any practical joint will have a thermal severity curve as shown in Figs. 7, 8, 9 and 10, the slope of which may be compared with those given in Figs. 18 (*a*) and 18 (*b*). Thermal severity curves for a number of typical joints have been obtained in the same way as those for the CTS series of tests, and these have been described in a previous paper.[3]

Where the thermal severity curve for a test is known, it is easy to calculate the cooling rate at 300° C for a weld of any given fillet size, made with the plates initially at room temperature. If the thermal severity of a joint is not known, then it may be possible to compare it with a joint for which the thermal severity is known, and so derive an approximate value for the rate of cooling. Some knowledge of the thermal severity of a joint is necessary to lay a fillet of sufficient size to ensure that the critical rate of cooling for the electrode/steel combination is not exceeded.

The Effect of Preheat on Cooling Rate

Where it is not possible, or desirable, to lay a fillet large enough to ensure that the critical cooling rate is not exceeded, some other means of reducing the cooling rate must be found. The usual method of doing this is by means of preheating. The effect of preheat on the CTS test has not yet been fully studied, but one test (TSN 6) has been made in which the assembly was preheated to 200° C. The root-rate curves for this test, and for a similar test without preheat, are given in Fig. 17. It will be seen that the cooling rate at 300° C has been effectively reduced from 10.3 centigrade degrees per second to 1.4 centigrade degrees per second. The effect of raising the initial plate temperature by 180° C has been to raise the major part of the root-rate curve by an almost equal amount, which would have been equal had the energy inputs to the two welds been equal. Thus the rate of cooling at 300° C in the preheated test would approximate to the rate of cooling at 120° C (300° C minus 180° C) in the nonpreheated test if the preheat was maintained during and after welding. Since preheat was not maintained during and after welding, the curves converge at room temperature.

THE EFFECT OF ELECTRODE TYPE ON WELDABILITY[4]

Test Procedure

In order to obtain a quantitative estimate of the weldability of a given plate of the Mn-Mo steel with various types of electrode from the BS 1719 classification, the test severity was varied by altering the size of the test weld deposit. Joint severity TSN 6 (trithermal flow in $^1/_2$-in. thick plates) was used with five different weld sizes, as shown in Table 8, having leg lengths of 0.15, 0.20, 0.25, 0.32 and 0.42 in. In this test two joints each having TSN 6 were produced on one assembly by extending the bottom plate of the CTS test by 3 in.

The energy input for each test weld and average values for each fillet size are given in Table 8, together with average cooling rates at 300° C in the hard zone.

Critical Cooling Rates for Various Electrodes

The results of the tests showed that there was a marked variation in liability to hard-zone cracking when welding with electrodes from the different groups. These results are given in Table 9, together with approximate critical cooling rates at 300° C for each electrode when welding the Mn-Mo steel. When the cooling rate is below the critical value no hard-zone

Table 8—Average Values for Energy Input, Fillet Size, Cooling Rate and Hardness Observed in the Tests with Various Types of Electrode

Electrode size, SWG	*Energy input,* joules per in.*	*Fillet leg length, in.*	*Avg. rate of cooling at 300° C, ° C per sec*	*Avg. peak hardness in heat-affected zone, DPN*
12	15,000	0.15	50	445
10	20,000	0.20	24	430
8	32,000	0.25	12	415
6	46,000	0.32	6	390
4	67,000	0.42	3.5	345

* Total arc energy.

Table 9—Relative Liability of Different Types of Electrode to Produce Hard-Zone Cracks When Welding $^1/_2$-In. Thick Manganese-Molybdenum Steel with Joint Severity TSN 6

Electrode type, BS 1719 coating group	*Hard-zone cracking* with various test fillet sizes†*					*Approximate critical cooling rate at 300° C, ° C per sec*
	0·15 in.	*0·20 in.*	*0·25 in.*	*0·32 in.*	*0·42 in.*	
1 Cellulosic	.....	Severe	Severe	Severe	Nil	4
2 Rutile	.....	Severe	Severe	Slight	Nil	5
3 Rutile-basic	.....	Severe	Severe	Nil	.....	7
4 Oxide-silicate	.....	Severe	Severe	Severe	Nil	4
5 Oxidizing	.....	Nil	Nil	.....	.....	Above 21
6 Low-hydrogen	Slight	Nil	Nil	.....	.....	30–40
Austenitic 18-8	Nil	Nil	.....	.....	.....	Above 43

* Severe cracking refers to coarse or fine cracks present in all three sections cut from the test weld. Slight cracking refers to microcracks present in one section only.

† Fillet size is expressed as average leg length.

cracks will be formed, but when the critical value is exceeded, cracking is likely to occur.

The great advantage to be gained by using group 6 (low-hydrogen) electrodes, instead of groups 1 (cellulosic), 2 (rutile), 3 (rutile-basic) or 4 (oxide-silicate) electrodes, is clearly shown in Table 9, and agrees with previous work by Sims and Banta.[9] The advantages of the austenitic and oxidizing electrodes, which are also shown in these results, were observed some years ago by Hopkin.[5] However, neither of these two electrodes combines all the advantages of the low-hydrogen type, since the austenitic electrodes are costly and the oxidizing electrodes give low weld strength.

This marked superiority of the group 6 (low-hydrogen) electrode has also been mentioned by Tremlett[10] in a recent paper. The use of electrodes of this type for welding the manganese-molybdenum steel should enable any thickness of plate to be welded with complete freedom from hard-zone cracking, provided that a minimum fillet size of $^1/_4$-in. leg length is deposited. With this fillet size 30 centigrade degrees per second is the maximum cooling rate obtainable at 300° C, even when welding on "infinitely" thick plates.

The value of average peak hardness in the heat-affected zone of each test weld was observed, and an approximate value is given for each weld size in Table 8. If this hardness value is greater than 380 DPN, hard-zone cracking is likely to occur with the group 2 (rutile) electrode, whereas values up to 400 DPN can be tolerated with the group 3 (rutile-basic) electrode. However, if the low-hydrogen electrode is used, values of up to 430 DPN in the hard zone can occur without hard-zone cracking.

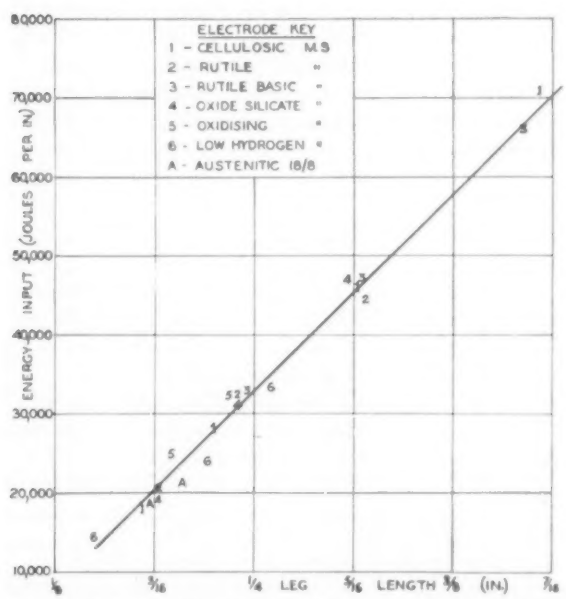

Fig. 19 Relationship between fillet size and energy input for electrodes from BS 1719 classification groups 1–6 and an austenitic 18–8 electrode

Relation Between Fillet Size and Energy Input

Values for energy input and fillet size have been observed in all the tests, and the results are plotted in Fig. 19, which shows that the relationship between these two quantities is linear for fillet welds of 0.15- to 0.4-in. leg length. This relationship is covered by the equation:

$$E = 2 \times 10^5 (L - 0.09) \quad \ldots\ldots\ldots (3)$$

where E is the total arc energy in joules per inch and L is the fillet leg length in inches. The use of different types of electrode has little effect on this relationship between energy input and fillet size, as indicated in Fig. 19. The plotting of values for both energy input and fillet size on the Y axis of the thermal severity curves in Fig. 18 should therefore be valid for all electrodes.

PROPOSED WELDABILITY INDEX[4]

It has been shown how a modification of the CTS weldability test can be used to assess the suitability of an electrode for welding a given steel. The CTS series of tests may also be used to determine the weldability of a steel. Difficulty arises, however, from the fact that different results for weldability will be obtained when different electrodes are used. For this reason it is necessary to find some means of expressing the weldability of a steel, which will take into account the suitability of the electrode.

A suggested scheme for obtaining a significant weldability index is given in Table 10. Fillet welds, each of

Table 10—Weldability Index

Critical cooling rate at 300° C, above which hard-zone cracks occur, ° C per sec	*Hard-zone cracking in 1/4 in. leg length fillet welds on CTS assembly*		*Weldability index letter**
	Present with TSN	*Absent with TSN*	
Over 32	.....	12 and under	A
20–32	12	8 and under	B
11–20	8 and over	6 and under	C
6–11	6 and over	4 and under	D
4–6	4 and over	3 and under	E
2–4	3 and over	2	F
Under 2	2 and over	....	G

* The BS 1719 electrode classification coating-group number should be placed before the index letter to complete the weldability index, e.g., for the steel tested the weldability index is 6A, 3D, or 2E.

1/4-in. leg length, are laid on tests of different severity, and examined for cracking. The steel is then given a weldability index letter, depending on which of the tests show cracking. The index is then completed by prefixing the coating-group number of the electrode used for the tests.

CONCLUSIONS

The relative effects of joint rigidity and rate of cooling on the initiation of hard-zone cracking have been studied in an attempt to resolve the two effects, and to provide a scientific basis for the correlation of weldability tests and structural joints.

It has been shown that the rate of cooling at 300° C in the heat-affected zone adjacent to the fusion line can be used as a criterion of weldability. When a critical rate of cooling, depending upon the steel and electrode, is exceeded, hard-zone cracking is liable to occur.

The existence of a constant critical cooling rate for a given electrode/steel combination in all tests, irrespective of the external restraint imposed, implies that the effect of external restraint is a minor one in the initiation of cracking. It has also been observed that the full-size Reeve weldability test is more severe than the corresponding miniature Reeve test. The reason for this difference becomes apparent when cooling rate is taken as an indication of severity.

A new test has been proposed with special conditions of heat flow. This test has a greater severity than the existing miniature Reeve test, which makes it more comparable with the severity of structural joints.

The test comprises four test assemblies using 1/4, 1/2, 1- and 2-in. thick material. The thickness of the plate used in each assembly controls the rate at which heat is conducted away from the weld. There are two test welds on each assembly, one bithermal and one trithermal, the latter being the more severe, because heat is conducted away more rapidly. In this way eight tests, each of different severity, are available on the four assemblies.

Each of the eight tests has been given a number, called the Thermal Severity Number (TSN), based on the thickness of material used. The series of tests, because of the various grades of thermal severity provided, has been called the Controlled Thermal Severity (CTS) test.

Cooling rates have been determined for the eight different grades of severity provided by the CTS tests using 1/4, 1/2, 1- and 2-in. thick material. These cooling rates, measured at 300° C, have been used in the construction of thermal severity curves. These curves have been drawn for the eight types of test weld, and have been found to conform to an empirical equation, their slope being an indication of the joint severity.

It has also been shown that there is a maximum attainable cooling rate for each level of energy input (fillet size). For a fillet weld of 1/4-in. leg length the maximum cooling rate is attained in a trithermal weld between 1-in. thick plates (TSN 12). The cooling rate is no greater when the same fillet size is deposited on 2-in. thick plates.

This limiting cooling rate has been found to be different for bithermal and trithermal welds. Two curves have been plotted for each of the above types of weld showing the maximum cooling rate attainable and these curves conform to another empirical equation.

A modification of the CTS test has been used to assess the liability to hard-zone crack formation when welding the Mn-Mo steel with electrodes from the various electrode coating groups given in the BS 1719 classification. The results of these tests have shown that ferritic electrodes having low-hydrogen and oxidizing coatings give good weldability, those having rutile-basic coatings give intermediate weldability and those having cellulosic, rutile and oxide-silicate coatings give the worst weldability. An austenitic 18–8 electrode was also tested and gave the best weldability.

A weldability index has been proposed with which it is possible to classify low-alloy steels in relation to their tendency to hard-zone cracking. The weldability of a given steel is denoted by one of the letters *A* to *G* in decreasing order of weldability. The weldability index letter depends to some extent upon the type of electrode used for welding the steel, and the letter is therefore preceded by the coating-group number of the electrode used.

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Deformation Twinning in Charpy V-Notch Specimens of Ingot Iron

The twinned region of a grain is not brittle and deformation twinning is not the cause of low-temperature embrittlement of ingot iron

by G. W. Geil and N. L. Carwile

Abstract

A metallographic study was made of deformation twinning in hot-rolled ingot iron deformed rapidly by impact at temperatures ranging from −196 to +100° C. As twins were observed in all of the specimens tested in this temperature range, deformation twinning in ingot iron is not restricted to a brittle behavior or deformation resulting in cleavage fractures. Twins were developed during the initial stages of plastic deformation and they apparently increased in breadth with increase in the strain of the specimens. The presence of many bent and severely distorted twins indicates that the twinned region of a grain apparently is not brittle and that deformation twinning is not the cause of low-temperature embrittlement of ingot iron.

INTRODUCTION

IN A STUDY of deformation twinning (Neumann lamellae) in specimens of ingot iron deformed rapidly in tension impact, Bruckner[1, 2] reported a direct association of deformation twins and the fracture of the specimen. He postulated that the twinning immediately precedes the fracture and the latter may be initiated by the stopping of the propagation of the twins at a barrier such as a subgrain boundary or other structural features that may be localized regions of large energy absorption. Tipper and Sullivan[3] made a study of the deformation twinning in silicon-ferrite crystals and reported that Neumann lamellae associated with fracturing occur only when the fractures are of the cleavage type. They suggested tentatively that the Neumann lamellae are initiated by the shock of the fracture itself in the unbroken material that is still severely stressed; some may be formed at the moment when the first break occurs or when something occurs to check fracture. They also reported that the evidence is in favor of the formation of the lamellae by cleavage, rather than that they contribute to the onset of cleavage.

A study at the National Bureau of Standards of the deformation twinning in specimens of hot-rolled ingot iron deformed slowly in tension at low temperatures was reported in a recent paper.[4] The results indicated a relation between the deformation twinning and the true strain* of the specimen. The deformation twins were initiated during early stages of the plastic deformation and the relative number of twins per unit area increased with increase in the deformation of the specimen up to a true strain value of about 0.06. Further deformation of the specimen produced very few, if any, additional twins. However, a general trend was observed of an increase in the breadth of the twins with increase in strain up to the fracture of the specimens. The data obtained did not show any evidence that a shock or shock wave set up at the fracture of the specimens produced any appreciable increase in the deformation twinning. Many bent and greatly distorted twins were also observed and there was no evidence that the twinned region was more brittle than the untwinned portion of the parent grain. The authors concluded that deformation twinning is not a cause of the low-temperature embrittlement of ingot iron.

In a recent study of deformation twinning in decarburized and carburized irons,[5] Low and Feustel report that a lateral growth of the twins was observed as the deformation of the specimen was increased, and that at relatively large deformations the twins and their parent grains were often highly distorted. Their observations on the occurrence of the twins also led them to conclude that deformation twinning does not cause the low-temperature transition in iron or contribute in any significant way to brittle fracture.

Rosenthal and Woolsey[6] presented the results of a study of deformation twinning in an annealed mild steel (AISI C1018) deformed in tension impact at temperatures ranging from −168° C (−270° F) to +25° C (+78° F) and at impact velocities varying from 11 to

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* True strain as used in this paper is the natural logarithm of the ratio A_0/A in which A_0 and A represent the initial and current minimum cross-sectional areas of the specimen, respectively.

0.001 fps. For testing temperatures above −112° C (−170° F) they observed a relationship between the impact velocity and a "threshold temperature," that is the highest temperature at which twinning occurred; the threshold temperature decreased with decrease in impact velocity. For temperatures of −112° C or lower they reported that the process of twinning appeared to be insensitive to the impact velocity or strain rate.

A study of the deformation twinning in Charpy V-notch specimens of hot-rolled ingot iron deformed rapidly by impact at temperatures ranging from −196 to +100° C has been made at the National Bureau of Standards and some of the phenomena observed are reported in the present paper.

MATERIAL AND TESTING PROCEDURES

Standard Charpy V-notch specimens were prepared from the central portion of a $^7/_8$-in. diam bar of ingot iron as hot rolled by the manufacturer. The principal chemical constituents (in percent by weight) other than iron are as follows: Carbon 0.2, maganese 0.02, phosphorus 0.005, sulfur 0.018, silicon 0.002, copper 0.10, oxygen 0.058 and nitrogen 0.002. The ferrite grain size of the iron varied considerably and the average grain size is given in Table 1 along with some of the mechanical properties of the iron at room temperature.

Table 1—Mechanical Properties at Room Temperature of Hot-Rolled Ingot Iron

Ferrite grain size, ASTM No.	4-5
Hardness, Rockwell B	32
Upper yield point, psi	29,600
Lower yield point, psi	24,700
Tensile strength, psi	43,300
Reduction of area, % at maximum load	23.2
Reduction of area, % at initial fracture	74.9
Reduction of area, % at final fracture	78.4
Elongation in 2 in., %	49.5

The notched-bar impact tests were carried out at temperatures ranging from −196 to +100° C in a Charpy machine of 224.1 ft-lb capacity, with a striking velocity of the hammer of 16.85 fps. The specimens, except the one tested at +25° C, were immersed in a bath at the desired temperature for a minimum period of 30 min and then quickly transferred to the impact machine and broken. The total time elapsing between the removal from the bath and the breaking of the specimen in the impact machine ranged from 3 to 4 sec, and there was no perceptible rise in the temperature of the specimen during this interval. The temperatures of the specimens in the refrigerant baths were measured by means of a calibrated Chromel-Alumel thermocouple and a precision potentiometer. For the tests at +50 and +100° C, the specimens were heated in a water bath in which a small amount of sodium chromate had been added as an inhibitor to corrosion.

Each specimen, after deformation by impact at the selected temperature, was sectioned longitudinally near the axis and mounted in bakelite. The preparation of the specimens for metallographic examination was carried out in the usual manner by mechanical polishing and etching. Vertical bright field illumination was adequate for examination at relatively low magnification (× 100). However, at high magnification (× 1000), oblique illumination generally revealed the deformation structures of the ingot iron more distinctly than vertical bright field, polarized light or sensitive tint illumination.

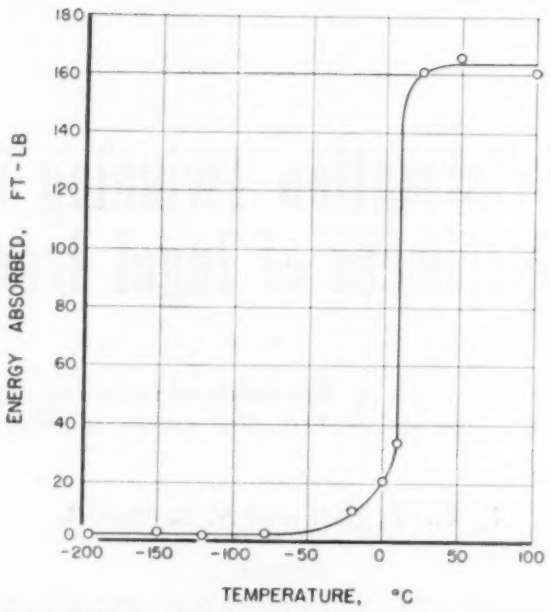

Fig. 1 Influence of testing temperature on impact energy of Charpy V-notch specimens of hot-rolled ingot iron

RESULTS AND DISCUSSION

The relation between the testing temperature and the energy absorbed in fracturing or as in many cases the partial fracturing of the Charpy V-notch specimens of hot-rolled ingot iron is shown in Fig. 1. As the principal purpose of this investigation was limited to a metallographic study of the deformation twinning in Charpy V-notch specimens deformed rapidly by impact, an insufficient number of observations were made to establish precisely the energy-temperature relationship and, therefore, the transition temperature range;* the data summarized in Fig. 1 are results obtained in only single tests at each temperature. It is pertinent to note the influence of the rate of deformation and testing method on the transition temperature range of the ingot iron. The transition temperature range (approximately −30 to +20° C) for the Charpy V-notch specimens deformed relatively rapidly by impact is very much higher than that (−150 to −196° C or lower) for unnotched tensile specimens of the same material deformed slowly in tension.[7]

* Transition temperature range, as used in this paper, represents the range of temperatures at which the behavior of the metal is partly brittle and partly ductile as indicated by the fracture appearance and the energy absorbed during the fracture or incomplete fracture of the specimen.

The metallographic examination of the deformation twinning in Charpy V-notch specimens of hot-rolled ingot iron deformed rapidly by impact revealed that the twinning features are similar in many respects to those reported in the previous paper[4] for tensile specimens extended slowly in tension at low temperatures. However, twinning occurred in all of the specimens deformed rapidly by impact at temperatures ranging from −196 to +100° C whereas in the specimens deformed slowly in tension it was limited mainly to those deformed at the lower temperatures of this range. Apparently the effect on deformation twinning of an increase in the rate of deformation is somewhat similar to that of a decrease in test temperature.

The extent and distribution of deformation twinning in the Charpy V-notch specimen were determined principally by the amount and distribution of the strain of the specimen. Some examples indicative of this feature are shown in Figs. 2 to 6 of longitudinal sections of specimens deformed at the designated temperatures. The twinning in the specimens broken by impact at −196° C (Fig. 2) and at −120° C (Fig. 3) is fairly representative of that in all of the specimens broken by impact at temperatures within the range of −196 to −78° C. As these temperatures are below the transition temperature range for the impact tests, the behavior of the ingot iron may be classified as brittle; very little energy (2 to 3 ft-lb) was absorbed during the fracture of the specimens, and the fracture surfaces appeared brittle. The deformation twinning in these specimens was limited to (1) a very narrow region adjacent to the fracture, (2) a narrow region adjacent to

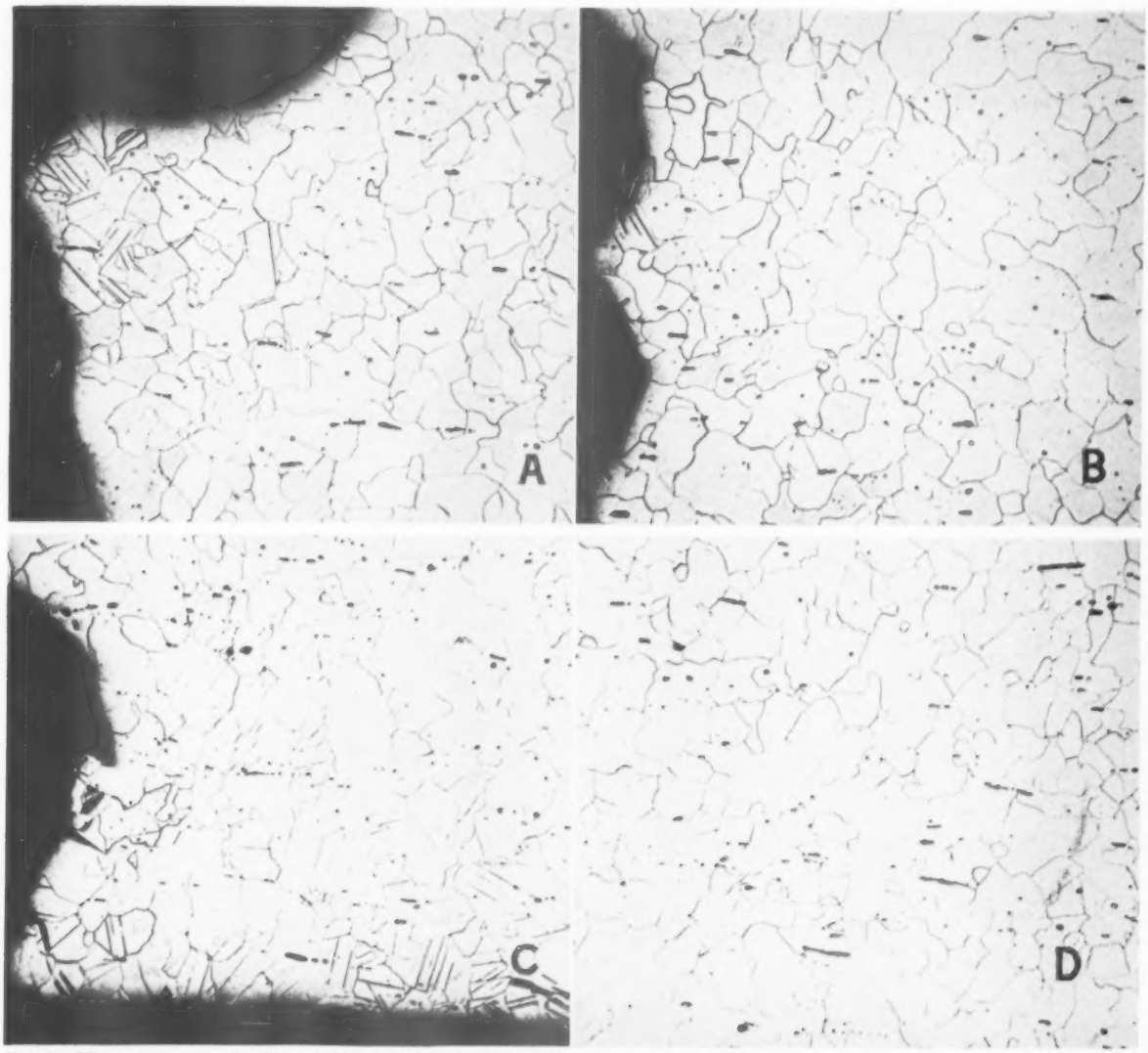

Fig. 2 Microstructure of a Charpy V-notch specimen of hot-rolled ingot iron fractured in impact at −196° C, longitudinal sections, × 100. Etchant: 1% solution of nitric acid in ethyl alcohol

A, Area at fracture and notch. *B*, Area at fracture, near center of specimen. *C*, Area at fracture and back side of specimen. *D*, Area, 0.05 in. from fracture, near center of specimen.

the root of the V-notch and (3) a relatively broad region in the back of the specimen at the position of impact of the hammer. From careful metallographic examination of specimens, the very narrow region of deformation twinning and plastic strain adjacent to the fracture (region 1) was observed to generally increase in width slightly with increase in testing temperature within the range of −196 to −78° C.

The deformation twinning patterns shown in Figs. 2 and 3 and also the similar patterns observed in the specimens broken by impact at −150 and −78° C (not shown) suggest a strain sequence as follows: The region at the back of the specimen adjacent to the position of impact of the hammer is elastically and plastically deformed under compression and twins are formed immediately after the instant of impact of the hammer. The specimen is bent elastically and the region adjacent to and under the root of the V-notch is subjected to very high tensile stress and deforms plastically to a small degree, resulting in the formation of twins near the root of the notch. Upon initiation of the crack, the metal just ahead deforms plastically by twinning; plastic flow also occurs by additional modes of deformation during fracture of the specimen as evidenced by the bending of the twins.

The deformation twinning in a Charpy V-notch specimen of ingot iron at a temperature within the transition temperature range is shown in the photomicrographs in Fig. 4 of longitudinal sections of a specimen deformed at −20° C. The energy absorbed was approximately 11 ft-lb, with incomplete fracture being characteristic of all specimens tested at this or higher temperatures.

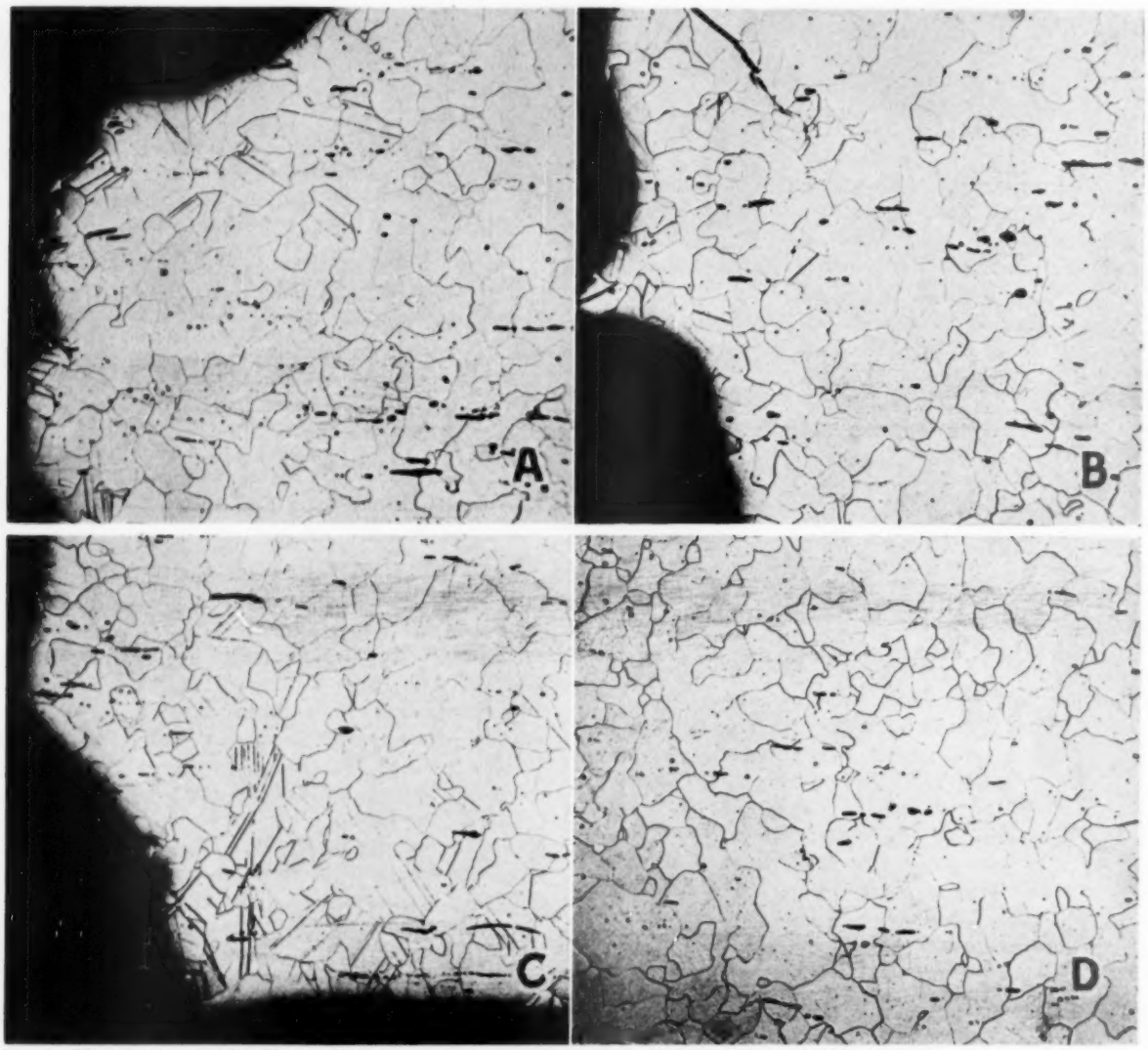

Fig. 3 Microstructure of a Charpy V-notch specimen of hot-rolled ingot iron fractured in impact at −120° C, longitudinal sections, × 100. Etchant: 1% solution of nitric acid in ethyl alcohol

A, Area at fracture and notch. *B*, Area at fracture, near center of specimen. *C*, Area at fracture and back side of specimen. *D*, Area 0.05 in. from fracture, near center of specimen.

The fractured surface appeared to be similar to that of the brittle fracture surface of specimens broken at temperatures below the transition temperature range. However, the specimen retained considerable ductility at this temperature as indicated by (1) the incomplete fracture, (2) the wide distribution of the deformation twinning and (3) the severe deformation of the specimen in the region between the end of the fracture and the back side of the specimen. The metal adjacent to the position of impact of the hammer also was severely deformed in compression (Fig. 4*C*) and the twins formed in this region were nearly obscured by the high degree of deformation of the grains subsequent to the formation of the twins.

Deformation twinning in the specimens tested in impact at 0 and +10° C (temperatures also within the transition temperature range) was similar to that shown for the specimen tested at −20° C. The region in which twins were observed generally increased with increase in the ductility and notch toughness of the iron as the testing temperature was raised from −20 to +10° C. The increase in the ductility and notch toughness was indicated by a decrease in the depth of propagation of the fracture, by a change in the appearance of the fracture surface and by an increase in energy absorbed during the impact test.

The deformation twinning illustrated in the photomicrographs in Figs. 5 and 6 is representative of that observed in specimens deformed by impact at temperatures slightly above the transition temperature range. The relatively few twins revealed in the specimen deformed at +25° C (Fig. 5) were partially obscured by the generally severe deformation of the iron. The fracture surface was almost completely ductile and a

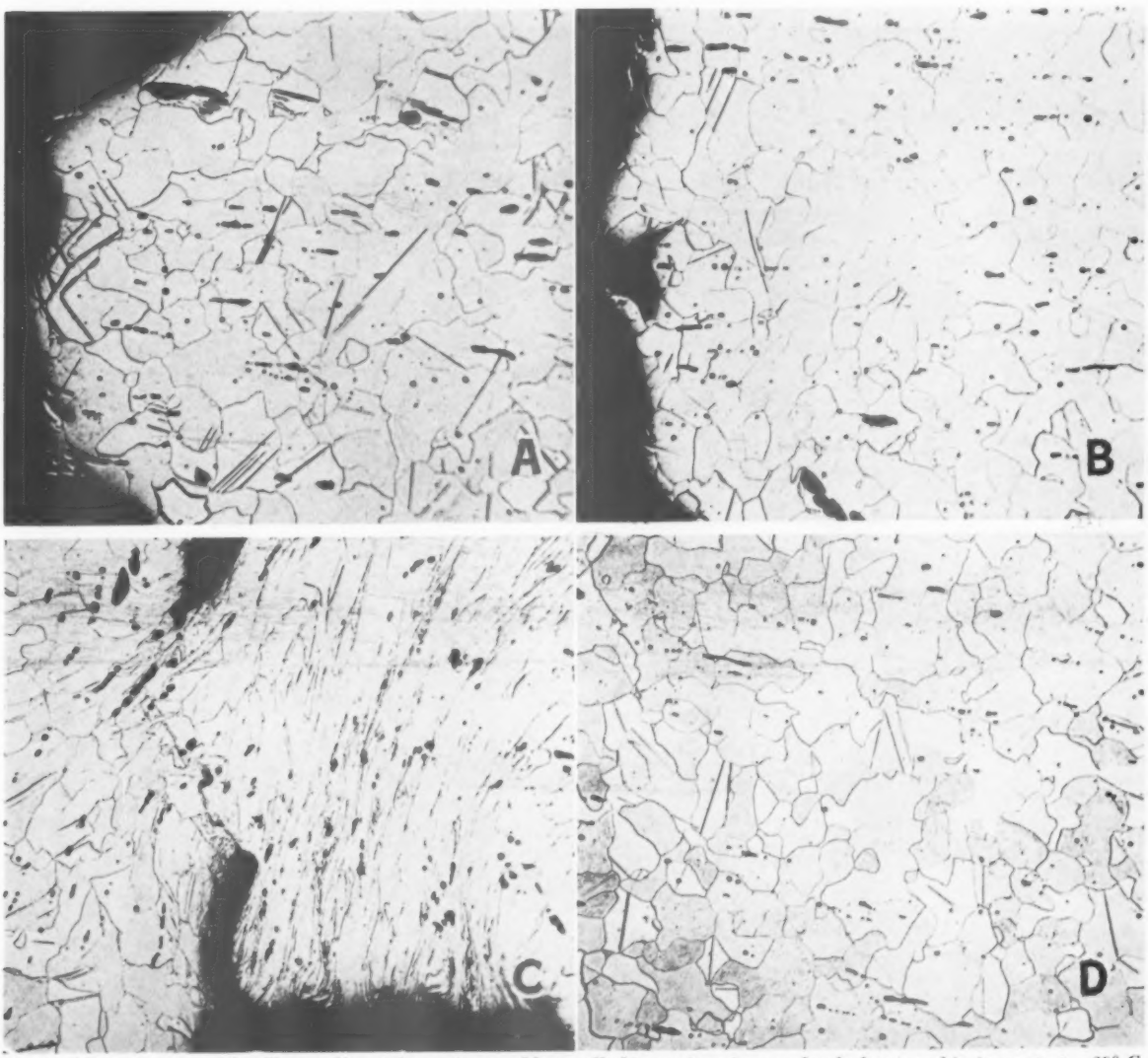

Fig. 4 Microstructure of a Charpy V-notch specimen of hot-rolled ingot iron incompletely fractured in impact at −20° C, longitudinal sections, × 100. Etchant: 1% solution of nitric acid in ethyl alcohol

A, Area at fracture and notch. *B*, Area at fracture, near center of specimen. *C*, Area at fracture and back side of specimen. *D*, Area 0.05 in. from fracture, near center of specimen.

relatively large amount of energy (160 ft-lb) was absorbed during the deformation of the specimen. The fracture was propagated only about one-half of the distance from the root of the notch to the back of the specimen. The specimens deformed by impact at +50° (not shown) and at +100° C (Fig. 6) also exhibited severe deformation and distortion of the grains. The energy absorbed during deformation was approximately the same as that of the specimen deformed at +25° C. The areas under compression at the back side of these specimens near the position of impact of the hammer were deformed much less severely than the corresponding areas of the specimens tested in the transition temperature range (Fig. 4) and at +25° C (Fig. 5). The fracture surfaces also appeared to be almost completely ductile and extended less than one-half of the distance from the root of the notch to the back of the specimen. The deformation twins apparently were more numerous and more readily discernible in the specimens tested at +50 and +100° C than at +25° C. The apparent minimum at +25° C in the degree of twinning in Charpy V-notch specimens conforms roughly to some results reported by Bruckner[2] in which he observed a minimum at +46° C (115° F) in the number of twins versus temperature relation for tension impact tests with ingot iron. However, this minimum in the twinning in the Charpy specimens during deformation by impact at +25° C may be more apparent than real as some of the twins formed in the specimen tested at +25° C may have been completely obscured by the severe deformation and distortion of the parent grains subsequent to the formation of the twins.

Photomicrographs at a magnification of × 1000 of longitudinal sections of the Charpy V-notch specimens tested in impact at temperatures ranging from −196 to +100° C are shown in Figs. 7 to 9. This series reveals

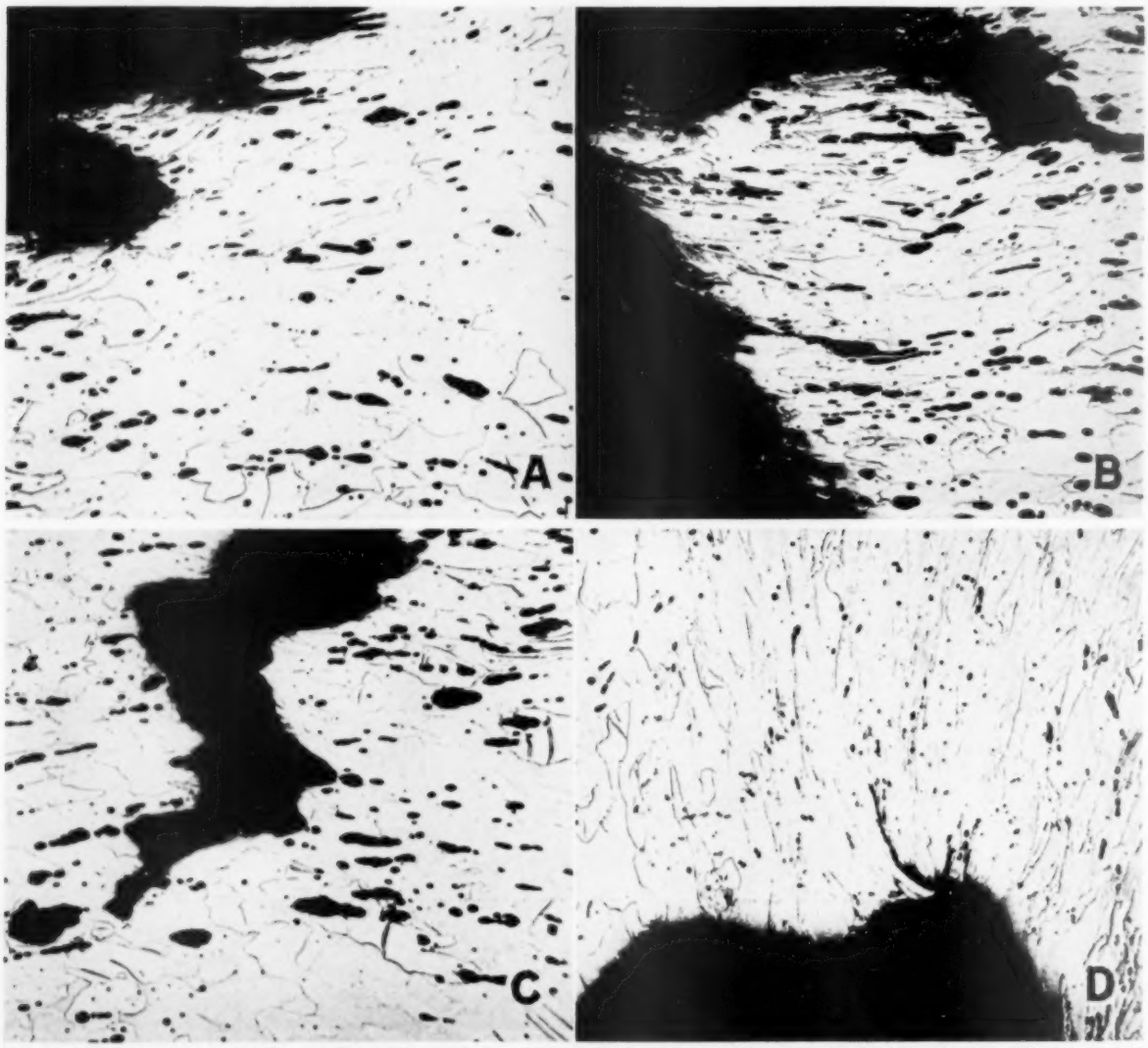

Fig. 5 Microstructure of a Charpy V-notch specimen of hot-rolled ingot iron incompletely fractured in impact at +25° C, longitudinal sections, × 100. Etchant: 1% solution of nitric acid in ethyl alcohol

A, Area at fracture and notch. *B*, Area at fracture, near center of specimen. *C*, Area at end of fracture. *D*, Area at back side of specimen.

some additional characteristics of the deformation twinning that are not revealed clearly in the photomicrographs at × 100. In a previous paper[4] the authors showed that deformation twinning in ingot iron deformed slowly in tension at −196 and −150° C was initiated during the initial stage of plastic deformation. The twins generally increased in size (breadth) with increase in strain up to fracture of the specimen. The metallographic study of the Charpy V-notch specimens deformed rapidly by impact indicates a general conformance to these relationships, although the impact data do not permit a quantitative determination of the strain. Large deformation twins were observed more often in the regions of the specimens that had received relatively large deformation than in the regions that had received relatively small deformation. Even in the specimens broken at −196, −150, −120 and −78° C with very little energy absorbed during the small total deformation and fracture, the twins formed in the grains adjacent to the fracture (Fig. 7, *B* and *D*) were generally broader than the twi ıs formed in the grains that were a few thousands of an inch distant from the fracture (Fig. 7, *A* and *C*). Many of the grains in or immediately adjacent to the fracture path in these specimens were deformed to a considerable extent prior to the fracture.

The photomicrographs in Figs. 7 to 9 also furnish some evidence that deformation twins in ingot iron retain considerable ductility and that the twinning apparently is not the cause of the brittle behavior of ingot iron at low temperatures. The numerous bent twins observed in the metallographic examination of these specimens (illustrated by Figs. 4*C*, 7*B*, 7*D*, 8*A*, 8*C* and 9) indicate that the twinned region *per se* retained considerable ductility. None of the data indicated that

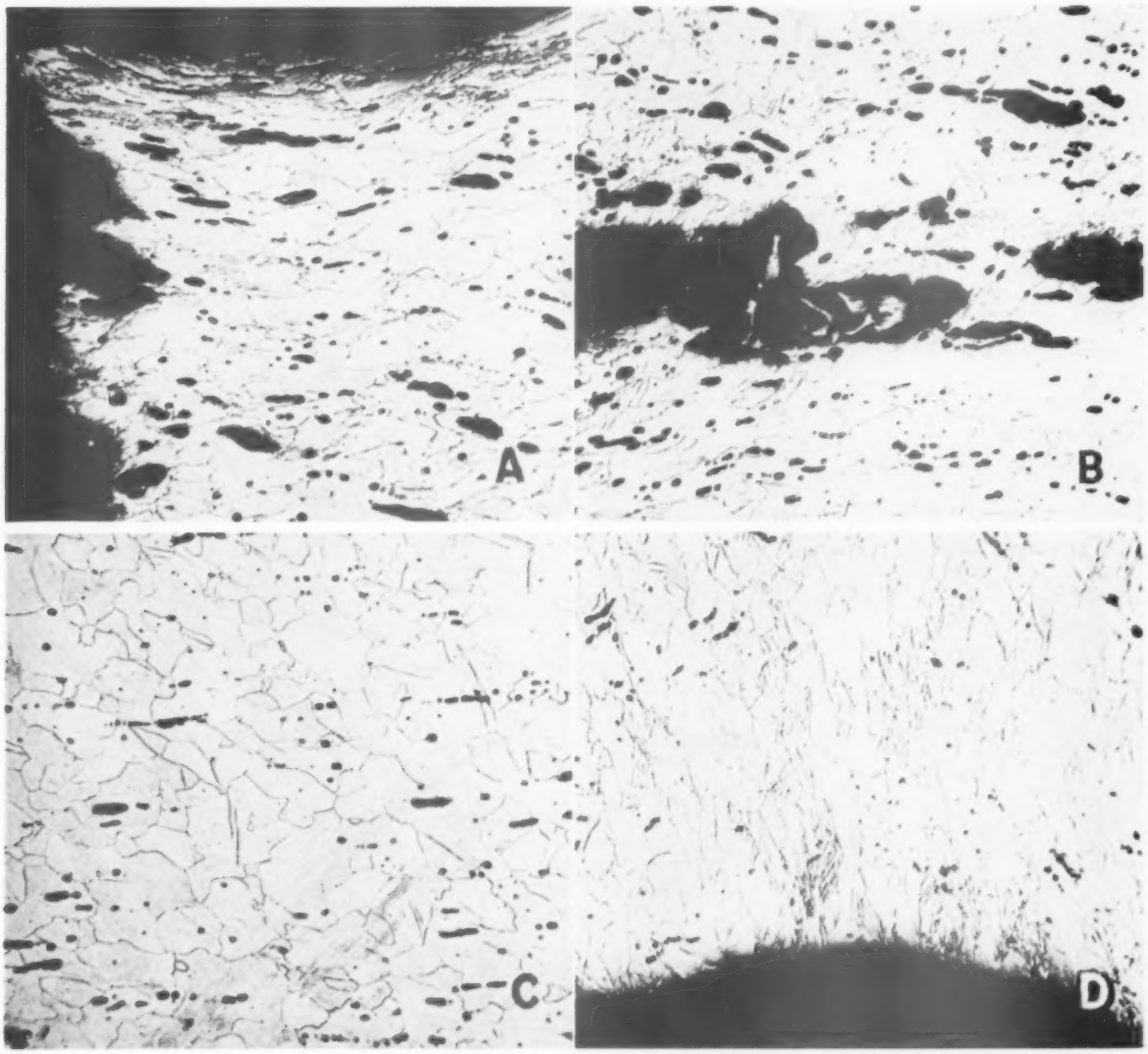

Fig. 6 Microstructure of a Charpy V-notch specimen of hot-rolled ingot iron incompletely fractured in impact at +100° C, longitudinal sections, × 100. Etchant: 1% solution of nitric acid in ethyl alcohol

A, Area at fracture and notch. *B*, Area at end of fracture. *C*, Area between fracture and back side of specimen. *D*, Area at back side of specimen, near position of impact of hammer.

the twinned region of the grain was more brittle than the untwinned portion of the parent grain. Even twins in the grains in or adjacent to the fracture surface in the specimens broken at temperatures below the transition temperature range were often bent severely (Fig. 7, *B* and *D*) by the general deformation and distortion of the parent grains subsequent to the formation of the twins and prior to the fracture of the grains. Severely bent twins in grains adjacent to the fracture were also observed in the specimens broken at −196 and −120° C.

Although the bending of the twins shows that the twinned region retains considerable ductility, it perhaps should be pointed out that this factor alone does not establish definitely that the twinned region is as ductile as, or more ductile than, the untwinned portion of the parent grains. However, deformation twinning in ingot iron may be regarded as a stress-relieving process with an accompanying increase in the ductility of the iron; the stresses in a grain or in several adjoining grains in a local region of high stresses are reduced considerably by the twinning, and the metal thereby may be subjected to further plastic deformation before the stress values increase to the critical stress necessary to initiate fracture. Thus, the ductility of specimens of ingot iron may be increased by deformation twinning. Moreover, unpublished data recently obtained at this laboratory from specimens of ingot iron tested in tension at low temperatures indicate that the twinned region of a grain is more ductile than the untwinned portion of the parent grain.

The deformed region of the specimen increased greatly in size and the distortion of the grains also increased with increase in temperature for temperatures

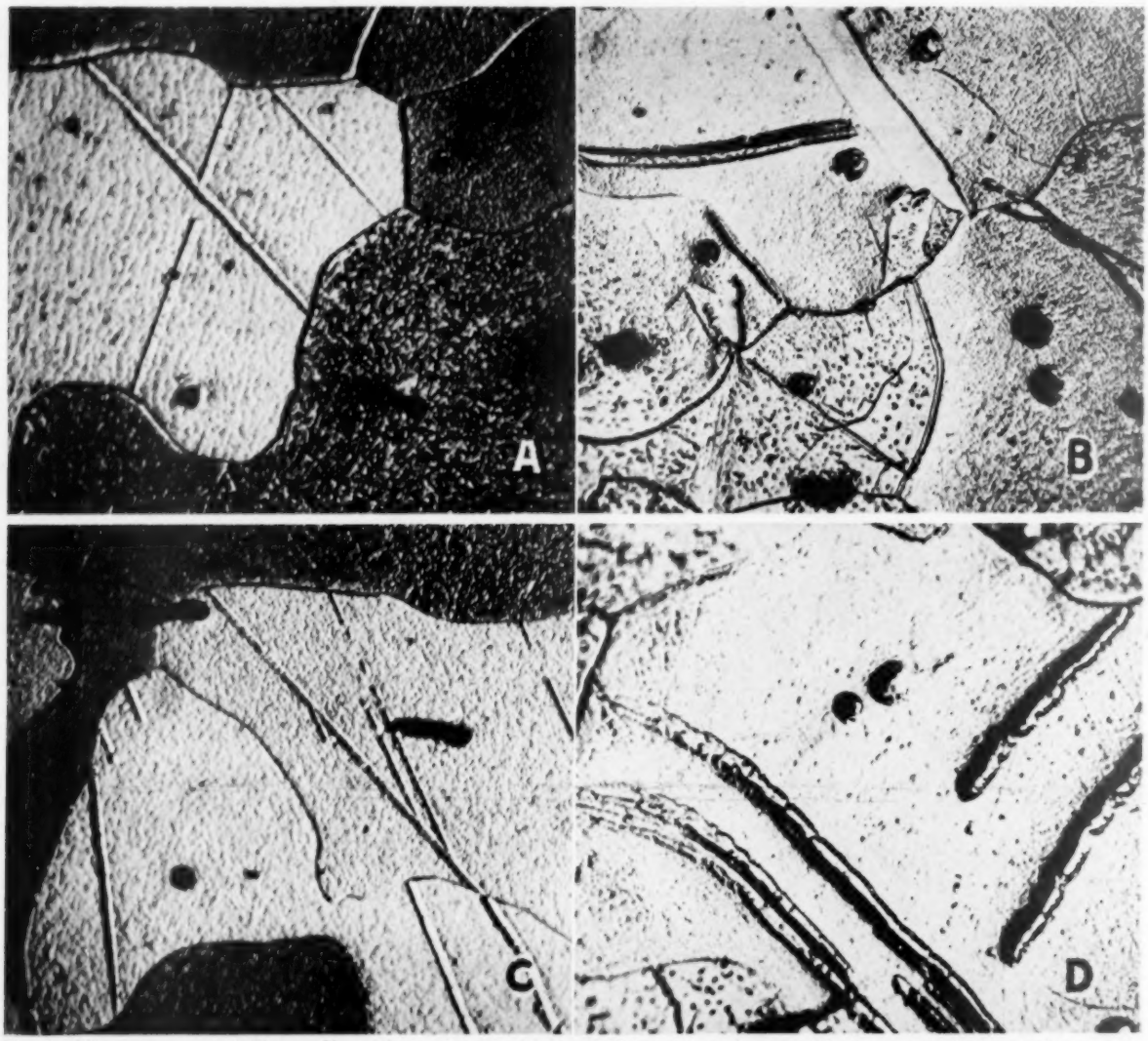

Fig. 7 Microstructure of Charpy V-notch specimens of hot-rolled ingot iron fractured in impact at designated temperatures, longitudinal sections, oblique illumination (left to right), × 1000. Etchant: 5% solution of nitric acid in amyl alcohol

A, −196° C, area near fracture. *B*, −150° C, area adjacent to fracture. *C*, −120° C, area near fracture. *D*, −78° C, area adjacent to fracture.

within or slightly above the transition range. The deformation twins shown in Fig. 8 are fairly representative of those observed in specimens tested at −20, 0, +10 and +25° C. The individual grains often were severely distorted and the twins, which apparently had formed early in the deformation, were severely bent and distorted along with the parent grain (Fig. 8). In some regions of severe deformation, the distortion of the grains partially, and in some instances perhaps completely, obscured the twinning that had occurred during the initial stages of the deformation.

Deformation twins were observed in the specimens tested in impact at +50 and +100° C (Fig. 9, *A* and *B*). Many of the twins in these specimens were bent and severely distorted, conforming roughly to the general distortion in the parent grains. This feature again indicates that the twinning occurs during the initial stages of the deformation.

The formation of deformation twins in the specimens tested in impact at temperatures above the transition range (temperature at which the behavior of the iron must be considered as ductile) also indicates strikingly that deformation twinning is not restricted to a brittle behavior of iron and that it apparently is not the cause of the brittle behavior of iron at low temperatures.

As deformation twins were observed in all of the specimens tested by impact at temperatures ranging from −196 to +100° C, a "threshold" temperature for twinning such as that reported by Rosenthal and Woolsey[6] could not be determined from these data; it apparently is above +100° C for hot-rolled ingot iron tested under the stress conditions existing during the

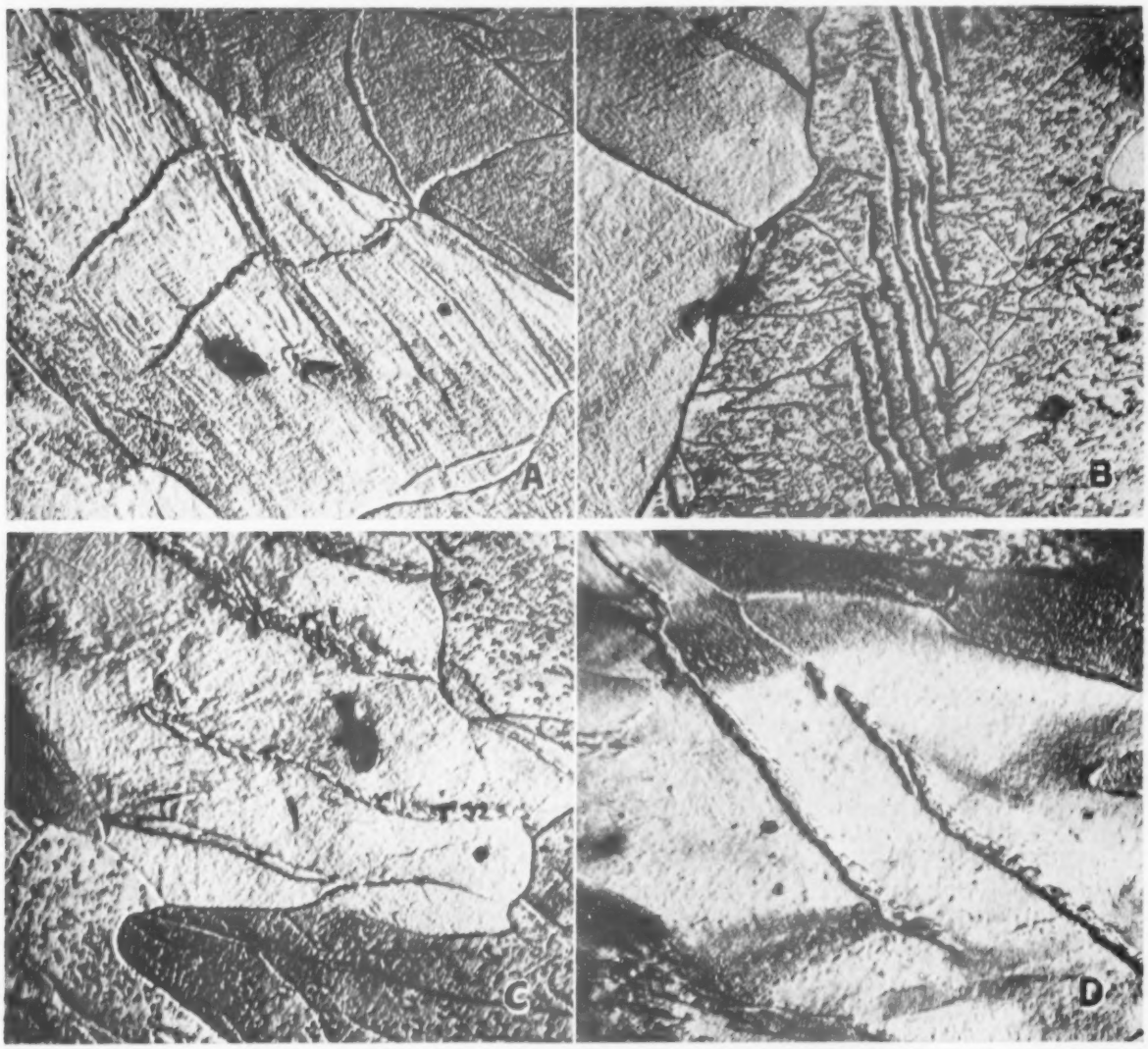

Fig. 8 Microstructure of Charpy V-notch specimens of hot-rolled ingot iron incompletely fractured in impact at designated temperatures, longitudinal sections, oblique illumination (left to right), × 1000. Etchant: 5% solution of nitric acid in amyl alcohol

A, −20° C, area between fracture and back side of specimen. *B*, 0° C, area between fracture and back side of specimen. *C*, +10° C, area between fracture and back side of specimen (near fracture surface). *D*, +25° C, area between fracture and back side of specimen (near back side of specimen).

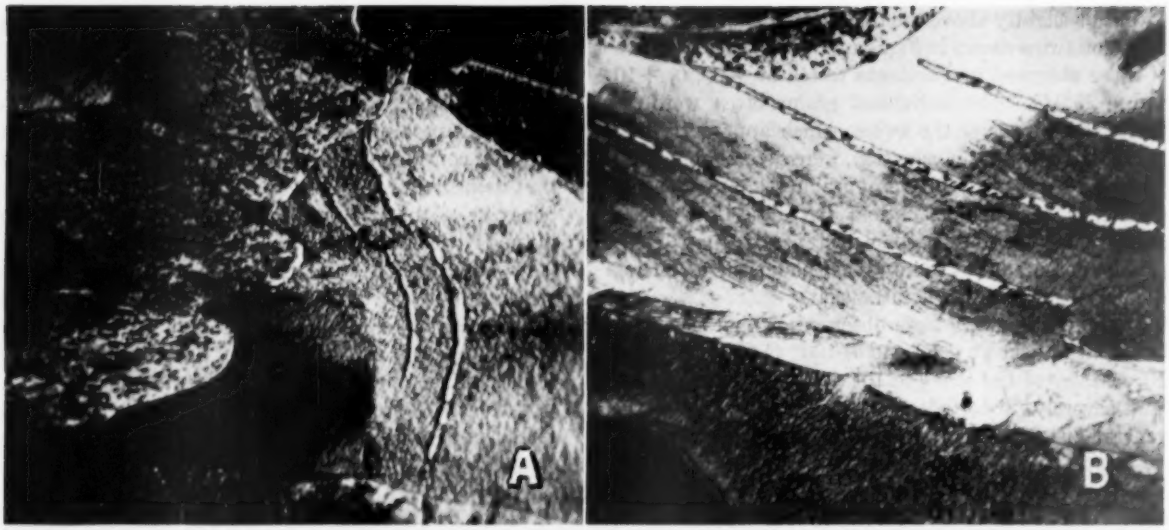

Fig. 9 Microstructure of Charpy V-notch specimens of hot-rolled ingot iron incompletely fractured in impact at designated temperatures, longitudinal sections, oblique illumination (left to right), × 1000. Etchant: 5% solution of nitric acid in amyl alcohol

A, +50° C, area between fracture and back side of specimen (near back side of specimen). *B*, +100° C, area between fracture and back side of specimen (near back side of specimen).

deformation of the Charpy V-notch specimens by impact. It is believed that the threshold temperature for twinning would be greatly affected by the stress systems existing during the deformation as well as by the strain rate. A determination of this factor would require much additional data and is beyond the scope of the present investigation.

SUMMARY

A metallographic study was made of deformation twinning in Charpy V-notch specimens of hot-rolled ingot iron deformed rapidly by impact at temperature ranging from −196 to +100° C. Deformation twins were observed in all of the specimens tested in this temperature range. The presence of twins in the specimens tested at +25, +50, and +100° C, which temperatures are above the transition temperature range of the iron, provides conclusive evidence that deformation twinning in ingot iron is not restricted to brittle behavior or deformation resulting in cleavage fracture.

The appearance and distribution of twins in the specimens broken in tests at temperatures below the transition temperature range of the iron furnish evidence that appreciable plastic deformation had occurred in certain regions in these specimens even though the fracture surfaces were of the brittle type and very little energy (2 to 3 ft-lb) was absorbed during the impact test. However, the volume of the specimen in which twinning and other modes of deformation occurred was relatively small.

Twins were developed during the initial plastic deformation of the iron and the twins apparently increased in breadth with increase in the strain during the impact test. The presence of many bent and severely distorted twins indicates that the twinned region of a grain apparently is not brittle and that deformation twinning is not the cause of low-temperature embrittlement of ingot iron.

ACKNOWLEDGMENT

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Effect of Atmospheric Contaminants on Arc Welds in Titanium

▸ *Minimum permissible content of oxygen, nitrogen, hydrogen and water vapor to avoid detrimental effects on the bend and tensile properties of welds*

by J. C. Barrett, I. R. Lane, Jr., and R. W. Huber

INTRODUCTION

IT IS a well-known fact that at high temperatures titanium metal is very reactive to gases such as oxygen, nitrogen, hydrogen and water vapor. These gases enter into solution with titanium, rendering it hard and brittle. For this reason titanium must be melted in an inert atmosphere, and in the shielded-arc welding process titanium must have much greater inert gas coverage than in the case of the more common metallic materials. Shielding on both sides of the weld is necessary, and a trailing shield behind the torch must be used to provide coverage for that portion of the weld that has solidified but that is still at high temperature.

In this paper the effect of gaseous contaminants on the properties of arc welds in titanium is studied, and an attempt made to determine the minimum content of each which would have a detrimental effect on the bend and tensile properties of the weld, under differing sets of conditions. This study is being carried forward by the Federal Bureau of Mines in cooperation with the Army Ordnance Corps, Watertown Arsenal.

PROCEDURE

Welding Equipment

The first step in such an investigation is to provide, for the purpose of control, a means of obtaining an atmosphere which would completely enclose the weld and exclude all atmospheric contaminants. To this end, a steel chamber was constructed, capable of being evacuated to 10 microns pressure and backfilled with the desired atmosphere. Figure 1 shows the equipment

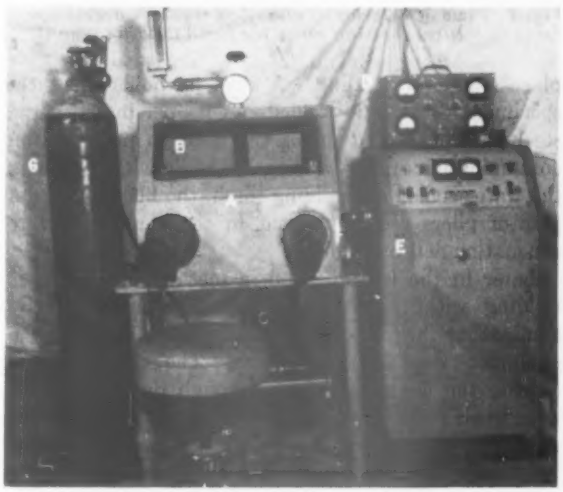

Fig. 1 Equipment for welding titanium in controlled atmosphere

used. Steel chamber *A*, with a volume of 4.7 cu ft, is fitted with an observation window *B*, which can be removed to gain access to the interior, and also has two holes in the front into which rubber gloves are inserted for the operator's hands. Vacuum pump *C* is used to evacuate the chamber, and a vacuum meter on the thermocouple ionization control *D* records the amount of vacuum. A leak detector, *E*, is also installed in the system. The system takes about 1 hr to evacuate if the chamber has been open any length of time; when the system has been closed, a vacuum of 10 to 15 microns can be obtained in 10 min. Connections to the welding torch, which is located within the chamber, are shown at *F*. The helium tank *G* (filled with high purity helium, 99.99% He) is used for backfilling the chamber after evacuation. Backfilling is carried out until a slight positive pressure is obtained, as evidenced by the swelling of the rubber gloves, as shown in Fig. 1.

In the earlier stages of this study, the welds were made by hand. Figure 2 shows the interior of the chamber as photographed through the access aperture with the glass window removed. Everything is in

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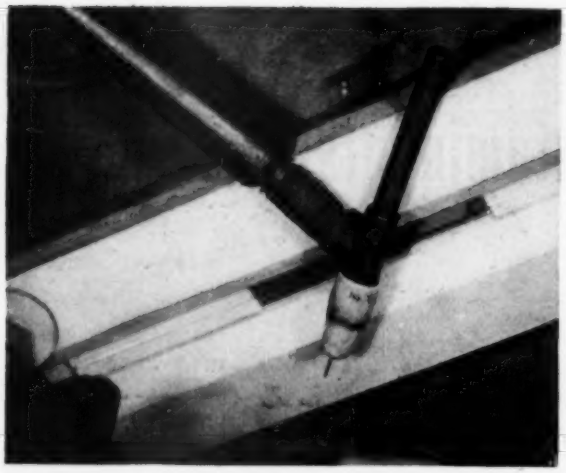

Fig. 2 View of interior of chamber through access aperture, showing setup for hand welding

place ready for welding. A steel jig holds the sheet specimens to be butt welded. A copper insert in the steel base is located under the weld to prevent iron contamination during welding. The jig with specimen, the water-cooled arc welding torch, the filler rod and a pair of pliers are all present in the chamber before evacuation and backfilling.

Later in the investigation, a method of automatic welding within the chamber was devised, thereby eliminating the personal factor. Figure 3, shows the equipment used for this purpose. The setup is shown outside the chamber, as not enough detail could be seen when photographing through the access window. Actual welding, however, was carried out in the chamber. The small traveling carriage which supports the welding torch is shown in Fig. 3. It is mounted on a steel track and can be run at speeds from about 5 to 72 ipm. The jig containing the pieces to be welded is also shown with the welding rod laid in the gap between the two pieces of sheet. The rod is tack welded at each

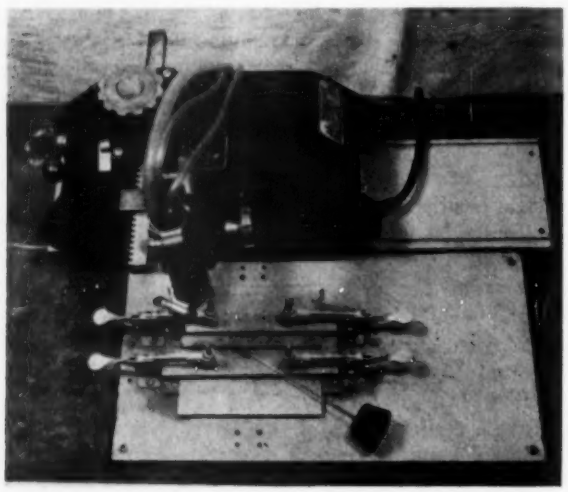

Fig. 3 Setup for making automatic welds

Fig. 4 Equipment for obtaining a water-saturated helium atmosphere

end, and then the torch is run automatically over the rod, thus making the weld. The small size of the chamber precluded use of a consumable electrode.

Equipment for Introducing Contaminants

The welds used for control purposes were made in an atmosphere of high purity helium. To obtain an atmosphere of helium saturated with water vapor (100% relative humidity), the setup shown in Fig. 4 was used. The helium flows from the cylinder through a bottle of distilled water by way of a fritted glass cylinder tube (note the agitation), through a glass tower filled with pyrex wool filtering fiber, and thence into the chamber. For lower relative humidities, the equipment shown in Fig. 5 was employed. A two-stage regulator *A* connected to the helium cylinder, allows helium to be delivered at various levels of constant pressure. The helium under pressure enters the saturator *B*, which is filled with distilled water and gravel.

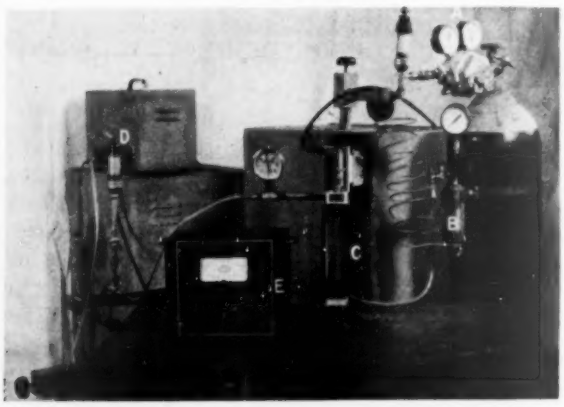

Fig. 5 Equipment for obtaining a helium atmosphere containing small amounts of water vapor

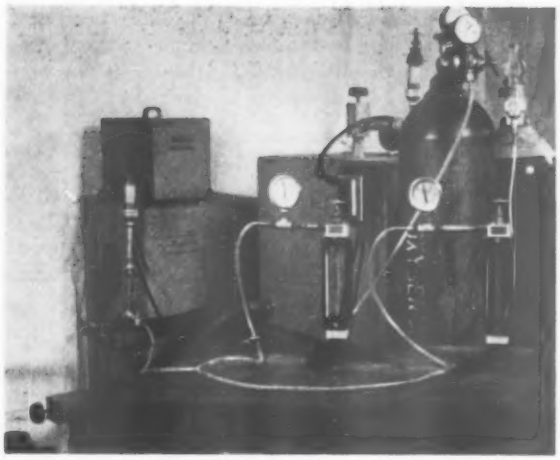

Fig. 6 Equipment for obtaining an atmosphere of helium with oxygen

The pressure in the saturator is the same as that on the low-pressure side of the regulator *A*. From the saturator the helium is fed through the flowmeter *C* at a rate of 40 cfh, and thence passes into the chamber. The higher the saturator pressure, the lower is the relative humidity of the helium passing into the chamber. Measurement of the relative humidity is made by means of an electric hygrometer *D* which is inserted into a short length of pipe above a bleed-off valve between the flowmeter and the chamber. The hygrometer windings are coated with a hygroscopic film which has the property of changing its electrical resistance instantly with microchanges in moisture content. There are several types of sensing elements, each covering a short range of relative humidity. Readings are taken from a standard a-c type indicator *E*, which registers humidity and temperature on an arbitrary scale. Use of curves which correct for temperature is necessary to obtain relative humidity.

When a mixture of helium and another gas is used, the mixing arrangement is as shown in Fig. 6. In this case the mixture is helium and oxygen. To obtain the desired composition of the mixture, a flowmeter and pressure gage are provided for each gas. The gases mix at a *Y* connection, and then flow into the chamber.

Regardless of the atmosphere employed, the chamber is first evacuated to 15 microns pressure and then backfilled with the desired gas or gas mixture prior to welding.

Materials

Commercially pure titanium sheet, 1/8 in. thick, and commercially pure titanium wire, 0.1 in. diam, were used for all tests reported. The hand welds were made with sheet and wire from one manufacturer, and will be referred to hereafter as Lot A sheet and Lot A wire. Stock for the automatic welds was made by a second manufacturer, and will be referred to hereafter as Lot B sheet and Lot B wire. Details of processing follow:

Lot A sheet—Arc-melted, hot-rolled, cold-rolled and vacuum-annealed; 1/8 in. thick.

Lot A wire—Arc-melted, originally 3/4-in. thick hot-rolled plate, hot-rolled and cold-swaged, with intermittent anneals, to 0.1 in. diam. Working from plate to wire was carried out at College Park.

Lot B sheet—Arc-melted, hot-rolled and pickled; 1/8 in. thick.

Lot B wire—Clippings 1/4 in. wide from Lot B sheet, cold swaged to 0.1 in. diam.

The carbon and nitrogen contents and average mechanical properties of the stock used are as shown in Table 1. Sheet stock tensile specimens were 6 in. long, with a measured section 1/2 in. wide by 2 1/4 in. long. Bend specimens were 6 in. long by 1 in. wide, and bent at the center around a pin of diameter four times the thickness of the sheet. Rolling direction in both bend and tensile specimens was longitudinal. Lot A wire was tested as an all-weld metal round specimen, subsize standard, 5/16-in. diam measured section. This specimen was made within the chamber in an atmosphere of pure helium, by filling a 3/4 x 3/4 x 7-in. titanium channel with weld metal obtained from Lot A wire.

From Table 1 one can see that Lot A sheet is stronger and more ductile in the bend test, than Lot B sheet. This should be borne in mind while viewing the results. This is contrary to general experience; usually lower strength and hardness are associated with higher ductility. Also Lot A wire as deposited is considerably stronger than Lot A sheet in spite of its lower carbon content; this was probably due to pickup of iron and oxygen during the fabrication processes.

The gases used in this work are as follows:

High purity helium, Bureau of Mines, 99.99% He.

Aviator's breathing oxygen, minimum 99.5% O_2, maximum water content 0.002 mg/l.

Nitrogen, minimum 99.5% nitrogen, maximum water content 0.013 mg/l.

Table 1—Chemical Analysis and Average Mechanical Properties of Original Stock

	Chemical analysis, %		*Mechanical properties*				
Stock	*Carbon*	*Nitrogen*	*Yield strength (0.1% offset), psi.*	*Ultimate strength psi.*	*Elongation in 2 in.*	*Bend (R = 2T), deg.*	*Vickers Hardness No.*
Lot A sheet	0.065	0.068	62,300	86,600	22.5	180, no break	200–210
Lot A wire	0.022	0.055	....	97,300*	20.0†	...	.....
Lot B sheet	0.048	0.018	44,200	74,400	23.0	150	160–170
Lot B wire	0.048	0.018	....	....	..	...	.....

* All-weld metal test bar (5/16-in. measured section 1 1/4-in. gage length).
† Elongation in 1 1/4 in.

Hydrogen, minimum 99.5% hydrogen, maximum water content 0.017 mg/l.

Additions of water to helium were made with distilled water.

Welding Procedure—Hand Welds

Hand welds were made with the equipment shown in Figs. 1 and 2. In all cases two pieces, 3 x 6 in., were butt welded along the 6-in. sides with rolling direction perpendicular to the weld. Edges to be welded were sheared. Welding variables were as follows:

Electrode: $^1/_{16}$-in. diam thoriated tungsten.
Gas flow into chamber: 40–45 cfh (except when water-saturated helium was used, in which case a flow of 10 cfh was used, as greater flows caused carry-over of water).
Welding current: 115–120 amp, d-c straight polarity.
Welding voltage: 15–21 v.
Welding speeds: 1.3 to 2.0 ipm.

In most cases the desired atmosphere was passed into the chamber only; in a few cases pure helium was passed through the torch to observe what protection such a procedure would have against contaminated atmospheres in the chamber. Flows of pure helium through the torch were about of the same magnitude as those of gases passing into the chamber.

Hand welds were made in the following atmospheres (in the chamber with no atmosphere through the torch, unless so noted):

1. Pure helium.
2. Helium saturated with water vapor at room temperature (25 mg/l).
3. As in 2, but with pure helium through the torch.
4. 90% helium, 10% nitrogen.
5. As in 4, but with pure helium through the torch.
6. 90% helium, 10% oxygen.
7. As in 6, but with pure helium through the torch.
8. 99% helium, 1% hydrogen.
9. 90% helium, 10% hydrogen.

Welding Procedure—Automatic Welds

Automatic welds were made with the equipment shown in Figs. 1 and 3. The same size pieces were sheared, and were welded as by the hand method. Because of the difference in methods, and because of higher welding speeds, somewhat higher current was used in making these welds. Welding variables were as follows:

Electrode: $^1/_{16}$-in. diam thoriated tungsten.
Gas flow into chamber: 40–45 cfh.
Welding current: 160–170 amp, d-c straight polarity.
Welding voltage: 19–21 v.
Welding speed: 5 ipm (this is the lowest speed obtainable with the carriage; all welds were made at this speed as representing the condition for maximum contamination).

Automatic welds were made in the following atmospheres (in the chamber with no atmosphere through the torch):

1. Pure helium.
2. Water vapor-helium mixture, 5% relative humidity (1.25 mg water per liter of helium)
3. Water vapor-helium mixture, 10% relative humidity (2.5 mg water per liter of helium).
4. 99% helium, 1% nitrogen.
5. 99% helium, 1% oxygen.
6. 90% helium, 10% hydrogen.

Tests of Welds

All welds were studied for outside appearance. Then each of the specimens was cut perpendicular to the weld to provide two tensile specimens ($^1/_2$ in. wide by $2^1/_4$-in. measured section), two bend specimens (1 in. wide) and one microspecimen. The microspecimen was also used for a Vickers Hardness exploration across the weld.

All bend specimens were tested by bending them around a bar the diameter of which was four times the thickness of the sheet. The face of the weld was subjected to the greatest fiber stress.

RESULTS

Appearance

Welds made in an atmosphere of pure, dry helium presented a clean bright appearance with no discoloration on the weld or adjacent to it. Figure 7 shows the appearance of two such welds, one made by the hand,

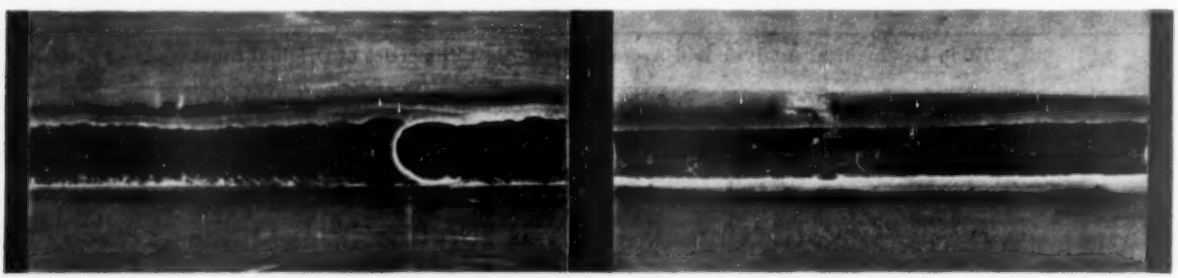

Fig. 7 Appearance of two specimens welded in a pure helium atmosphere. (Left) hand weld. (Right) automatic weld

Table 2—Properties of Hand Welds

Weld No.	Atmosphere in chamber	Atmosphere through torch	Nitrogen content, %	Tensile properties: Yield strength (0.1% offset), psi.	Tensile properties: Ultimate strength, psi.	Tensile properties: % Elongation in 2 in.	Tensile properties: Location of break*	Bend properties: Bend angle (R = 2T), deg.	Bend properties: Broken	Vickers hardness: Parent metal	Vickers hardness: Maximum in weld
1	Pure He	None	0.033	66,700	86,500	18.0	P	180	No	200–205	220
				65,000	86,700	17.5	P	180	No		
2	He saturated with H_2O vapor	None		75,200	88,200	4.5	EW	30	Yes	190–200	275
				74,100	89,700	5.0	EW	25	Yes		
3	He saturated with H_2O vapor	Pure He		61,200	86,600	17.0	P	180	No	200–210	225
				61,500	86,700	18.5	P	120	Yes		
4	90% He 10% N_2 by volume	None	0.70	65,200	72,400	1.0	EW	0	Yes	200–210	460
				63,400	79,300	3.5	EW	17	Yes		
5	90% He, 10% N_2 by volume	Pure He	0.047	66,200	87,800	22.0	P	180	No	200–205	230
				68,900	88,400	22.0	P	180	No		
6	90% He 10% O_2 by volume	None	...	†	†	†	...	0†	Yes	200–205	480
7	90% He 10% O_2 by volume	Pure He		64,200	89,100	22.0	P	90	Yes	200–205	230
				68,100	88,500	16.0	P	130	Yes		
8	99% He 1% H_2 by volume	None		64,900	87,000	18.5	P	180	No	200–210	220
				64,500	86,800	22.5	P	160	Yes		
9	90% He 10% H_2 by volume	None		63,700	89,000	19.0	P	125	Yes	200–210	240
				63,800	87,800	20.0	P	95	Yes		

* Key to symbols: P—parent metal, W—weld, EW—edge of weld.
† Both tensile bars and one bend test broke in machining.

the other by the automatic method. The comparative smoothness and uniformity of the latter can be noted.

Welds made in an atmosphere of helium containing water vapor had a bluish cast and a roughened appearance which were more noticeable as the water content of the atmosphere was increased. When a nitrogen-helium atmosphere was used, the resulting weld had a dull varicolored blue and golden appearance which was again more marked with increase in nitrogen content. Oxygen-helium mixtures turned the weld gray, and white deposits of TiO_2 were in evidence in the vicinity of the weld. The only effect of hydrogen in a helium atmosphere was to impart a slightly tarnished appearance to the weld, scarcely noticeable when the 1% hydrogen-helium mixture was used, but more so after exposure to the 10% hydrogen-helium mixture.

Tensile, Bend and Hardness Tests

Tables 2 and 3 show the tensile and bend properties of the hand and of the automatic welds, respectively. Hardnesses in the center of the weld and in the parent metal are also shown. Nitrogen contents of welds made in nitrogen-helium atmospheres were obtained. As there is no equipment at College Park for oxygen and hydrogen analyses, these could not be made.

The welds made in pure helium, both hand and automatic, have tensile and bend properties comparable to those of the parent metal, with the exception of elongation. This property is lower in the welded specimens due to the metallurgical changes in them and to the rigidity of the weld itself. When the helium is saturated with water vapor or contains 10% oxygen or 10% nitrogen, the welds are rendered hard and brittle, so

Table 3—Properties of Automatic Welds

Weld No.	Atmosphere in chamber	Atmosphere through torch	Nitrogen content %	Tensile properties: Yield strength (0.1% offset) psi.	Tensile properties: Ultimate strength psi.	Tensile properties: % elongation in 2 in.	Tensile properties: Location of break*	Bend properties: Bend angle (R = 2T) deg.	Bend properties: Broken	Vickers hardness: Parent metal	Vickers hardness: Maximum in weld
10	Pure He	None	0.017	48,100	78,400	18.5	P	160	Yes	160	200
				48,500	77,800	15.0	P	130	Yes		
11	He and H_2O vapor, 5% relative humidity	None	...	49,500	78,600	13.0	P	130	Yes	160	270
				45,700	78,000	16.5	P	90	Yes		
12	He and H_2O vapor, 10% relative humidity	None	...	50,200	78,500	12.5	P	115	Yes	160	250
				48,800	78,900	11.5	P	115	Yes		
13	99% He, 1% H_2, by volume	None	0.17	50,000	76,500	6.0	W	35	Yes	160	370
					34,600†	00.0†	P and W	50	Yes		
14	99% He 1% O_2 by volume	None	...	50,800	78,700	10.5	P and W	30	Yes	160	340
				47,000	76,300	10.5	P and W	30	Yes		
15‡	90% He, 10% H_2 by volume	None	...	65,600	92,900	12.5	P	40	Yes	200	250
				62,600	90,200	18.5	P	60	Yes		
16§	Pure He	None	...	48,500	74,400	15.0	P	180	No	160	240
				47,100	79,200	17.5	P	180	No		

* Key to symbols: P—parent metal, W—weld, EW—edge of weld.
† Apparently contained flaw ignore results.
‡ Made from a different heat of material than the rest of the welds in the table. Properties are comparable to those of parent metal.
§ Welded with Lot A wire.

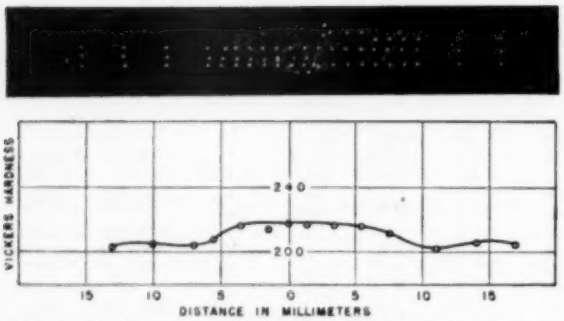

Fig. 8 Hardness survey on weld made in dry helium atmosphere

much so in the oxygen-helium atmosphere that cracks developed and three out of four of the test pieces broke in machining. It is interesting to note that higher yield strengths were observed in the welds made in an atmosphere of water-saturated helium than in the other welds; this is so in spite of the fact that the tensile breaks occurred in the parent material, which showed no hardness increase. This phenomenon is to be studied further.

The properties of the weld made in a 1% hydrogen–99% helium atmosphere were as high as those of dry helium welds except in bending. A slight lowering of ductility occurred when the hydrogen content was raised to 10%. Apparently hydrogen is not as effective an embrittling agent as oxygen or nitrogen.

Full preservation of properties occurred when a weld made in a 10% nitrogen–90% helium atmosphere was protected by passing dry helium through the welding torch. Partial preservation of properties occurred when the weld was protected from the 10% oxygen–90% helium mixture.

Even when the content of oxygen and that of nitrogen was cut to 1% by volume (Table 3) embrittlement was apparent in the resulting weld specimens, as evidenced by both weld hardness and bend test results. Diminishing the water content in helium served to improve weld properties almost to the level of the properties of the welds made in pure helium. The hardness in these welds, however, is still relatively high.

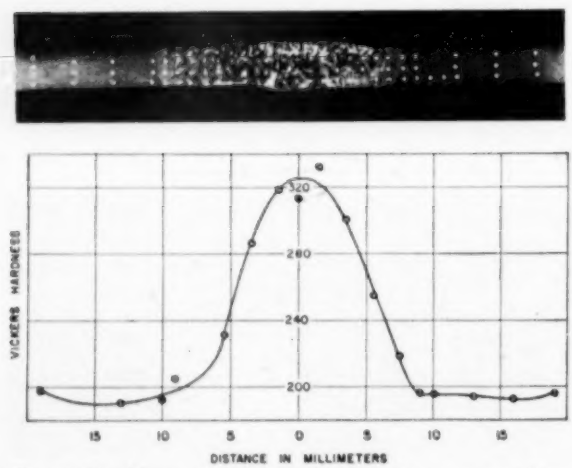

Fig. 9 Hardness survey on weld made in an atmosphere of helium saturated with water vapor

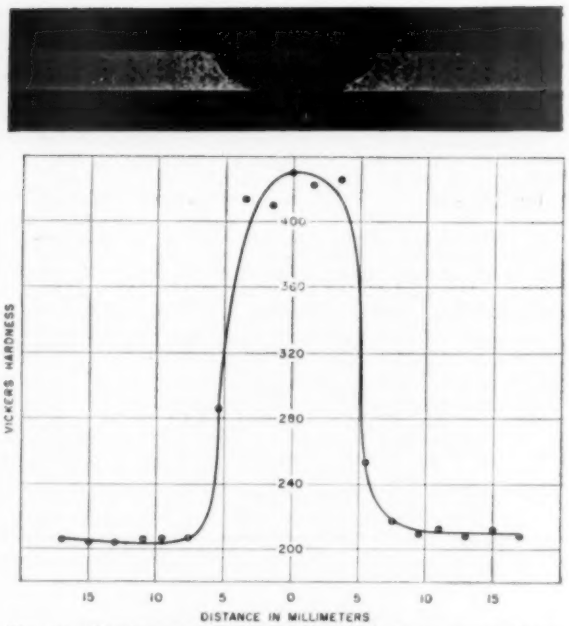

Fig. 10 Hardness survey on weld made in an atmosphere of 10% nitrogen and 90% helium

It was observed before that Lot B stock, both sheet and wire, was both less strong and less ductile than Lot A stock, and it can be seen from the tables that this difference is carried over to the weld specimens. To illustrate this, a weld (No. 16) was made in a pure helium atmosphere with Lot B sheet and Lot A wire. The strength and ductility were raised in comparison with welds made from Lot A material. Lot A material is more desirable than Lot B material for these tests, and future experiments will be carried out, if possible, with stock of properties close to those of Lot A stock.

Pickup of nitrogen in welds made in nitrogen-helium atmospheres is noticeable, the contents being 0.70 and 0.17% nitrogen for the 10% nitrogen-helium atmosphere and the 1% nitrogen–helium atmosphere, respectively. According to a report from Battelle Memorial Institute,* a nitrogen content of as low as 0.13% is high enough to cause weld embrittlement. It is significant that when protection against a nitrogenous atmosphere was offered by passing dry helium through the torch (Weld No. 5, Table 2), the nitrogen content was only slightly above that in a weld made in pure helium. Tensile and bend properties of this weld are as good as those of the pure helium weld, as would be expected.

Macrostructure and Microstructure

A portion of each weld made was sectioned for macrostructure and microstructure studies. These specimens

* D. C. Martin and C. B. Voldrich, Final Report to Air Materiel Command on "The Effects of Carbon, Oxygen, and Nitrogen on the Properties of Welds in Titanium Sheet."

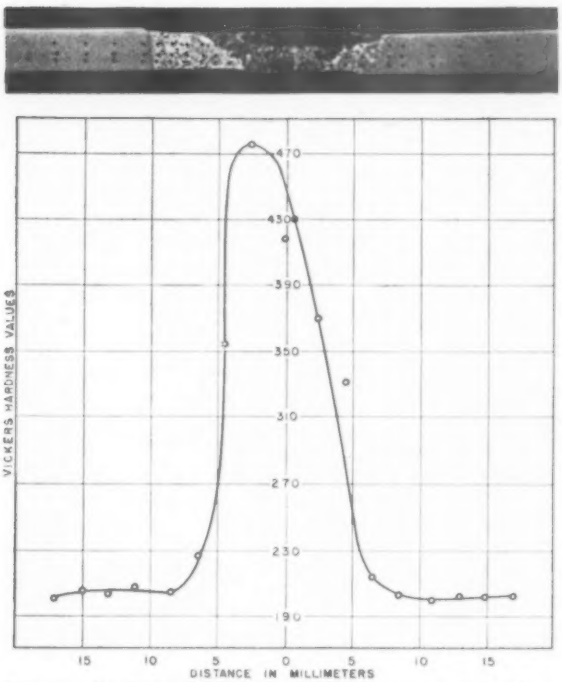

Fig. 11 Hardness survey on weld made in an atmosphere of 10% oxygen and 90% helium

were also used for hardness surveys. Figures 8, 9, 10 and 11 show the macrostructure and hardness exploration of welds made in the following atmospheres:

Fig. 8. Pure helium.
Fig. 9. Helium saturated with water vapor.
Fig. 10. 10% nitrogen–90% helium.
Fig. 11. 10% oxygen–90% helium.

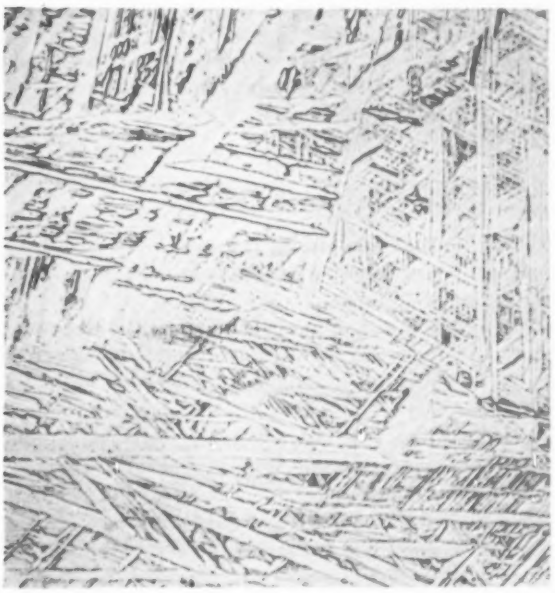

Fig. 12 Structure at weld center of weld made in pure helium atmosphere. Keller's etch. 500×

Fig. 13 Structure near top in weld made in 10% nitrogen–90% helium atmosphere. Structure consists of untransformed alpha (large needles) and transformed alpha. Vickers hardness impressions can be seen (100-g load). Keller's etch. 500 ×

Figures 10 and 11 show the high hardness gradient that occurs when oxygen or nitrogen is added to the helium atmosphere. A coarsening of the grain size is noticeable in these welds (somewhat masked in the 10% nitrogen-helium weld because of the formation of alpha needles high in nitrogen) and in the weld made in water-saturated helium, as compared with the pure helium weld.

Figure 12 shows the microstructure of the pure helium weld at 500×; the Widmanstätten structure typical of cast titanium is evident. The microstructures of welds in atmospheres containing water and in hydrogen-helium atmospheres are comparable to Fig. 12, with the exception of the grain coarsening. Figure 13, taken near the top of the 10% nitrogen-helium weld, shows the structure of the alpha needles at 500 ×. This alpha, high in nitrogen, is a primary, untransformed product. Due to the high nitrogen content, the solidified melt, with dropping temperatures, passes through the alpha plus beta field; the needles then are untransformed alpha, and the remainder of the microstructure is alpha which transformed from the higher temperature beta. As one progresses from the top to the bottom of the weld, the needles are less in evidence, until a nearly normal Widmanstätten structure appears at the bottom of the weld. In Fig. 13 the high hardness of the nitrogen-rich alpha needles (933 Vickers) is observed, in contrast to the hardness of the transformed alpha (383 Vickers). That this weld contained cracks, which have a tendency to follow the alpha needles,

Fig. 14 Cracks in weld made in 10% nitrogen–90% helium atmosphere. Keller's etch. 500×

is demonstrated by Fig. 14. No alpha needles were observable in the weld made in the 1% nitrogen-helium atmosphere.

The structure in the center of the weld made in the 10% oxygen-helium weld was a typical Widmansättten

Fig. 15 Cracks in weld made in 10% oxygen–90% helium atmosphere. Keller's etch. 500 ×

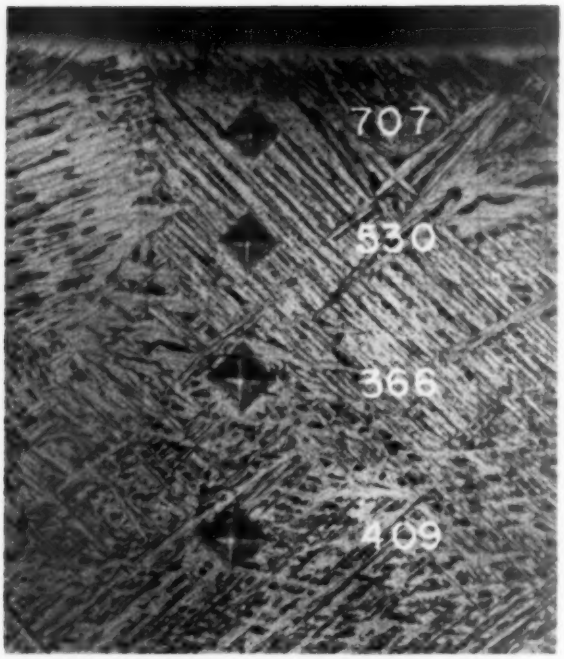

Fig. 16 Hard crust at top of weld made in 10% oxygen–90% helium atmosphere. Vickers hardness impressions can be seen (100-g load). Keller's etch. 500 ×

structure comparable to that of welds made in pure helium but, of course, far higher in hardness. Cracking was also present in this weld, as shown in Fig. 15. The top surfaces of this weld and of the weld made in the 1% oxygen-helium atmosphere were composed of a slow-etching crust, high in oxygen and of high hardness. This crust is shown in Fig. 16; its hardness is higher than that of the subsurface structure, as evidenced by the hardness impressions. The crust was narrower and softer in the case of the weld made in the 1% oxygen-helium atmosphere.

Welds made in both the 10% nitrogen-helium and the 10% oxygen-helium atmospheres contained porosity at the edge of the weld; all the other welds were sound.

CONCLUSIONS

With the data obtained, and under the conditions described, the following tentative conclusions can be drawn:

1. A weld in titanium made in a pure helium atmosphere has properties comparable to those of the parent metal, as tested in tension and bending.
2. The relative humidity of the helium atmosphere should be lower than 5% for welds to be comparable with those made in pure helium.
3. Helium atmospheres containing nitrogen or oxygen must contain considerably less than 1% by volume of these gases singly if properties are to approach those of welds made in pure helium. Severe embrittlement occurs when these gases (singly) comprise 10% of the gaseous mixture.

4. Hydrogen is not as detrimental to weld tensile and bend properties as is oxygen or nitrogen since a weld made in a 1% hydrogen–99% helium atmosphere showed properties nearly comparable to those of welds made in a pure helium atmosphere. An increase in hydrogen to 10% resulted in no drastic lowering of the tensile and bend properties.

5. Protection from a contaminating atmosphere within the chamber can be provided by passing dry helium through the welding torch, and in most cases full preservation of tensile and bend properties results.

FUTURE WORK

This paper is in essence a progress report. The tests described above will be continued in an attempt to arrive at that content of each gas contaminant below which the mechanical properties are not affected, and above which they are affected. Analyses of the various gaseous mixtures, both at the inlet and exhaust of the chamber, as well as analyses of weld metal for oxygen, hydrogen and nitrogen contents will be obtained. Welding speeds will be varied and various degrees of protection and atmosphere turbulence will be tried to observe the effects of these factors. When the simple mechanical tests, such as tensile and bend, have narrowed the search, fatigue tests and corrosion tests will be carried out on welds made in several gaseous mixtures. The effect of sheet thickness will be studied. When the work on commercially pure titanium is completed, the investigation will be extended to include various titanium alloys.

ACKNOWLEDGMENT

The authors wish to express their thanks to the personnel of Watertown Arsenal, particularly C. E. Hartbower, for technical assistance in this work.

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To What Extent Does Stress Relieving Occur at 200–300° C?

Heating below 300° C has a minor effect on the internal stresses of the weld metal but at this temperature the residual stresses in the base metal is reduced to two thirds

by R. Gunnert

NOW and then the thought has cropped up to submit a welded vessel to a so-called low-temperature treatment, which should mean a heating of the welded object to a temperature of 200–300° C instead of an annealing at 550–650° C. Large vessels are rather awkward to heat to such a high temperature. They demand a large furnace and expensive arrangements. At a lower temperature the heating may be done with the aid of superheated steam, a liquid with high boiling point or the like, thus an expensive furnace could be dispensed with.

There is some doubt whether, in fact, such a high stress relieving occurs at 200–300° C that there occurs any substantial improvement of the welded object. This problem was dealt with at the 1951 IIW Congress at Oxford, and a separate Committee was appointed for this purpose. To throw a little light on this question I have carried out some research work in order to ascertain what really happens to the stresses when heating to temperatures between room temperature and about 300° C.

The research result by O. Forsman and K. G. Olsson,[1] published in 1947, was the initial inspiration for my investigation. I will return to this later on.

THEORETICAL VIEWPOINTS

To start with we will have a closer look into how metal in general reacts to stresses. Suppose that we produce stresses by monoaxial load of an object. In other directions than the loading direction the loads and stresses are nil.

Figure 1 illustrates how the material—e.g., a test specimen—is affected by a load. The load or stress is marked out along the ordinate, and on the abscissa the extension resulting from this stress on a gage length of 50 mm. The graph is called a stress-strain diagram.

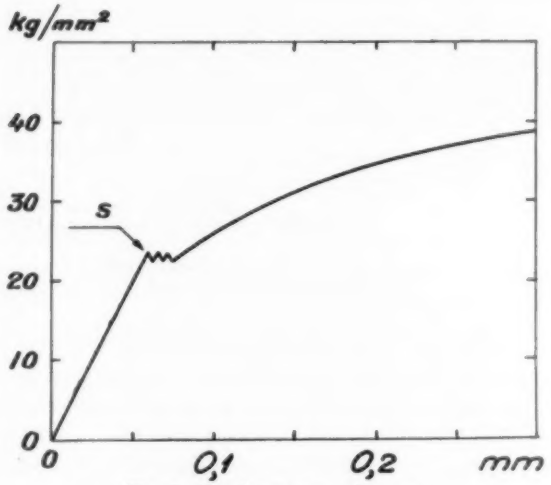

Fig. 1 Strain—stress—diagram

We see that in the beginning the elongation rises practically proportionally to increasing stress, until the point *S* is attained. The stress existing at this point is called the upper yield point and is designated σ_{yu}. If the load is taken away here or at some lower value, the loaded object will almost entirely resume its original shape—the elongation has been elastic. If the load is increased the stress drops, to begin with, to σ_{yl}—the lower yield point—and increases then gradually—work hardening range. When unloading the loaded object will no longer resume the original state, the elongation is plastic. The stress range σ_{yl}–σ_{yu} is called the yield point range, and, as is custom, we shall in the following call σ_{yl} for σ_y, the yield point.

The upper broken line in Fig. 2 illustrates schematically the conditions at room temperature. It is the same at higher temperatures, which is shown by the lower lines; here the slope of the straight line in the elastic range differs.[2] The relation between stress σ and elongation ϵ, which relation is usually designated by the letter E, is a little less at higher temperatures

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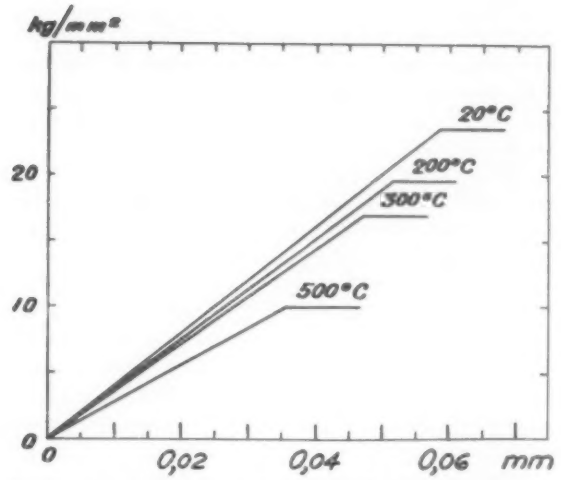

Fig. 2 Strain—stress—diagram at different temperatures

than at room temperature. However, we should now attach the greatest attention to the lowering of the yield point. The stress that could be applied before the heated object gets into the yield point range will become less and less.

From Fig. 2 the following may be concluded. An object may be loaded up to a certain stress σ_y. If this yield point stress is exceeded, the material will yield to the load, and the yield point stress σ_y will practically not change. The material yields. It should then be so that if a stress is applied on an object, this stress can maximally amount to the yield point σ_y. The yield point σ_y occurs at lower stresses, the higher the temperature of the object. In a welded object there may be stresses consequently, which attain the yield point as a maximum—we understand a monoaxial stress. At higher temperatures there are thus smaller stresses in the object than at room temperature. By heating the object is brought to yield at a lower stress. When cooling down to room temperature the stresses are retained that were present at the higher temperature, provided, naturally, that no new stresses occur by too rapid cooling, etc.

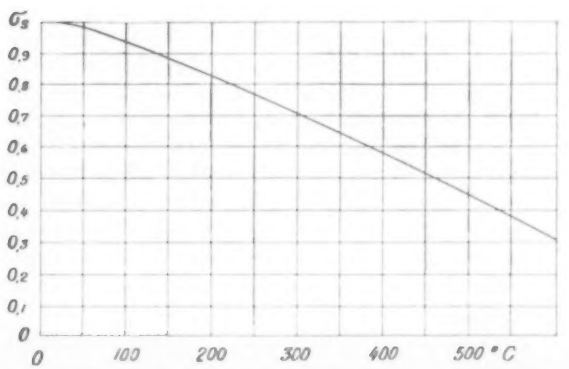

Fig. 3 The yield point of mild steel at different temperatures

Stresses which are lower than the yield point at the temperature in question are not affected in this way; e.g., a stress of 15 kg/sq mm in Fig. 2 is still at 200° C, 15 kg/sq mm, and even after cooling down to room temperature it is 15 kg/sq mm, whereas it decreases when heating to 500° C, because it is higher than the yield point at this latter temperature.

Figure 3 is a clearer picture of the yield point for mild steel at higher temperatures. The diagram is made according to Smith.[3] The yield point of the material at room temperature was 30 kg/sq mm. This diagram, as well as the following ones, is made so that the stress that for the material in question corresponds to the yield point at room temperature—in this case 30 kg/sq mm—is set to = 1. In this way one avoids the confusion of ideas which may arise by the fact that material with different yield points at room temperature will be dealt with in this work.

If the material follows the scheme which I have now outlined above, the same decrease of the stress should follow at heating to some of these temperatures. E.g., heating to 300° C should reduce the yield point by approximately 30%; then even a monoaxial stress ought to be reduced by the same amount, 30%. To ascertain the truth of this supposition a number of tests was carried out. The point was partly to find out whether the stress reduction keeps pace with the reduction of the yield point, partly to see whether the duration of the heating had any effect. This cannot perhaps be expected, because the creep below 350° C is of minor effect.[6]

MONOAXIAL STRESSES

The main point of the problem is, as always, to find the right test method. The question is to get monoaxial stresses of different values. These stresses, which must be "had for the asking," will then be treated in the manner I select—e.g., I heat the object with the stress to 200° C and measure the stress afterward. The stress must thus be present in a place where I can measure it exactly.

Figure 4 shows the testing device. In a piece of mild steel, with the dimensions 170 x 150 x 50 mm, was drilled and milled an oval hole according to the figure. Centrally through the piece was drilled a 20-mm hole, through which a specimen was put. The specimen was provided with a nut at either end. By tightening the nuts the specimen was subjected to a stress, the size of which was dependent on the extent of tightening. In order not to load the bar with torsion, one end was provided with a hole to bear against when screwing up the nut.

The specimen itself was provided with four warts according to Fig. 5. In these warts conical holes had been drilled, which served as support points for measuring balls of a measuring instrument, by means of which the distances between these holes were carefully ascertained before and after each tightening of the nut. When the nut was screwed tight, the distances were ex-

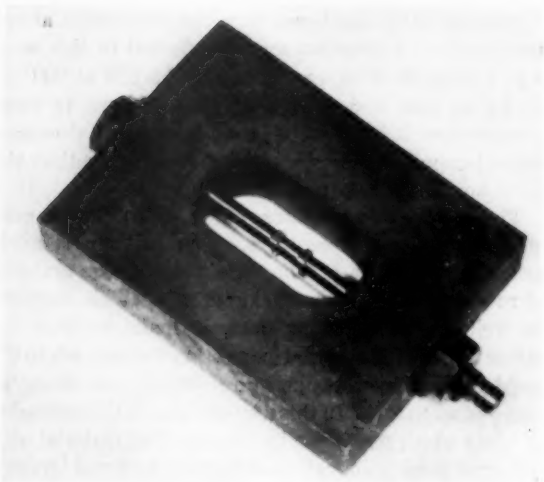

Fig. 4 The testing device

tended, and from the extension the applied stress may be estimated as per the formula: $\sigma = E \cdot \epsilon$, where σ is the stress, E the modulus of elasticity = 20,000 kg per sq mm and ϵ the strain.

When loosening the nut the distances are shortened. From the shortening one can estimate in the same way the stress that was present in the bar before the loosening. If, e.g., the bar has been heated after screwing tight and before loosening the nut, the two stresses measured in the aforementioned way will not be equal. Consequently, one can measure the reduction in stress that has occurred by the heating. The screwing up must be carefully done, so that the yield point of the material at room temperature is not exceeded, because then the figures will be false.

As will be seen from Fig. 5 the warts are such that the stress flow through the bar will be as undisturbed as possible. For the same reason smaller fillet radii where the threaded ends begin have been avoided as far as possible. Otherwise there would be a too early yielding in certain parts of the bar, and it would be impossible to make tests near the yield point.

Because a slight bending of the bar cannot be avoided, the mean value of the readings on both sides of the bar was ascertained at each measuring, and in the following I have used these mean values. The difference between the readings on the two sides was very slight.

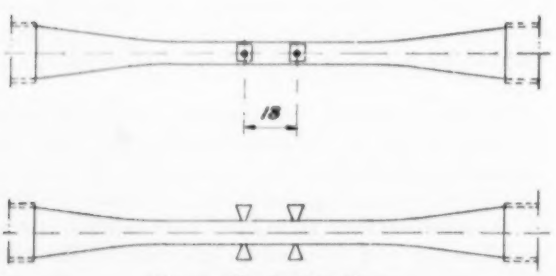

Fig. 5 The test specimen

The material in the bar was mild carbon steel. A bar of this material was inserted in a Losenhausen tensile testing machine and was stretched to breakage. The diagram of elongation/stress is the one shown in Fig. 1, σ_{yu} was 23.3 and σ_{yl} 22.4 kg/sq mm. The tensile strength of the bar was 41.1 kg/sq mm.

At the tests outlined in the above the bar must consequently not be stressed above σ_{yu} 23.3 kg/sq mm, because then one enters into the work-hardening range with a higher yield point as a consequence. None the less, should this be the case, one must either reject the specimen or find out the new, higher yield point and then continue with the tests in relation to this. The new yield point is determined by alternately stressing and measuring the bar. When a little yielding has been established, the new yield point is attained, which is thus determined.

The heating of the test device was done in an ordinary muffle oven. Before testing the oven was started in good time so that it was well up in temperature when the test device was inserted. The time of heating was measured from the moment when the specimen (at room temperature) was placed in the hot oven until the moment it was taken out of the oven. As a rule the specimen has been taken out of the hot oven and allowed to cool in still air. An examination proved that it is not necessary to let the test device cool down in the cooling oven. The temperature shown by the oven thermometer was checked, and it was found to show 10° in excess. The following figures are corrected accordingly.

The measurings were carried out as follows. First the bar was strained with the nut, the distance l_1, so that almost the yield point at room temperature was attained, i.e., $E \cdot l_1/18 \sim \sigma_y$, where E equals 20,000 kg/sq mm.

Then the test device was heated. After having cooled down perfectly, the distance between the conical holes was measured again, and the nut unscrewed. The distance was once again measured. The difference between these two measurings was l_2, which gives the shrinkage $\epsilon = l_2/18$.

By determining again the hole distance after heating it was checked that no sliding had occurred in the nut threads or the like. Of the shrinkage ϵ one obtains the remaining stress σ from the formula: $\sigma = E \cdot \epsilon$.

In Fig. 6 the figures obtained are indicated by points. For various temperatures up to the vicinity of 300° C each point thus indicates the stress present in the bar after the bar had been heated to the respective temperature. When put into the oven the bar was in all cases loaded with a tensile stress only slightly below the yield point at room temperature σ_y. The measured, remaining stresses are reduced with regard to the fact that the yield point has been set to 1, as previously. The bar, clamped in the test device, has in all cases been lying in the oven for 16 hr.

Between the points in Fig. 6 a graph has been drawn. This is, in fact, the same graph as in Fig. 3! It fits in rather well to and between the measured values.

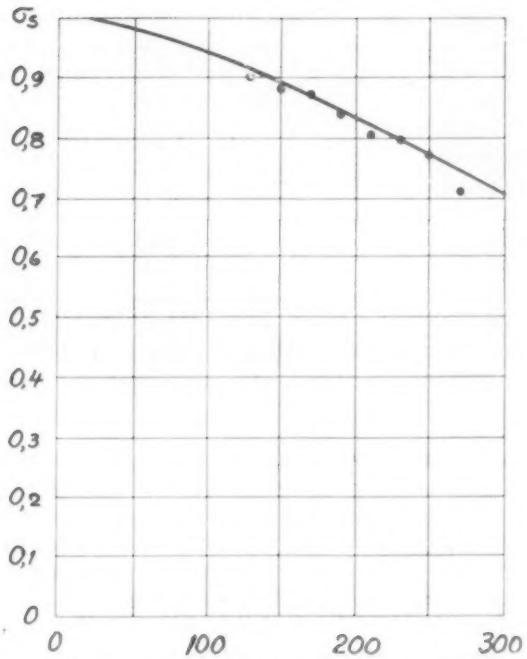

Fig. 6 The stresses at different temperatures as parts of the yield point

I should take this test result as a complete verification that when heating an object with monoaxial stresses, these stresses will be reduced to the same value as the yield point of the material at the temperature in question.

I have formerly pointed out that if the stress in the bar before heating is too low, there will be no reduction of stress. If the original stress is lower than the yield point at the heating temperature, this stress should thus not change at the heating process.

Figure 7 confirms this. Along the abscissa is marked out the stress prevailing in the bar when inserted in the oven, and along the ordinate the measured stress after heating. The heating temperature was in this case 190° C and the time, as before, 16 hr. We see that a stress, which was originally at the yield point = 1, was reduced to 0.84. This was also the case with an original stress of 0.90. A stress, which was originally 0.75 and even lower, did not change by the heating. Between these two stresses, 0.75 and 0.90, there was a certain stress reduction according to the graph. Theoretically the original stresses up to 0.84 should not change. However, this was indeed the case, and that is due to the difficulty to avoid bending the bar somewhat when being loaded. Local yielding in the bar will follow, even if the mean stress has not attained the yield point.

I should like to mention that the stress dropped to the same value as indicated in Figs. 3 and 6 at the heating temperature 190° C, namely to 0.84.

The question is: Would it be possible to obtain this stress relieving with a shorter heating time than 16 hr?

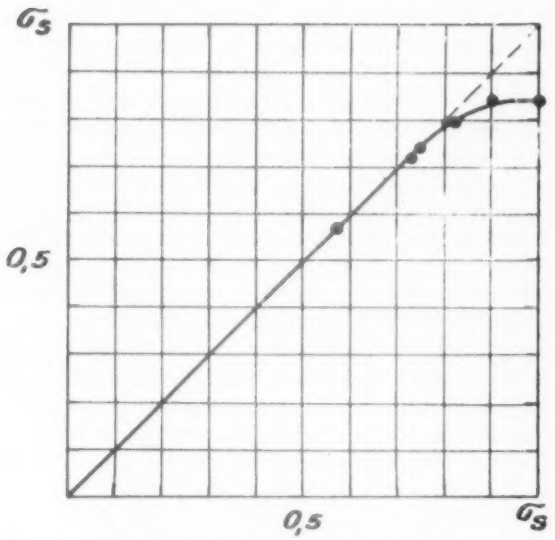

Fig. 7 Residual stresses when the origin stresses were different

Or would a still longer time of heating give a greater stress reduction?

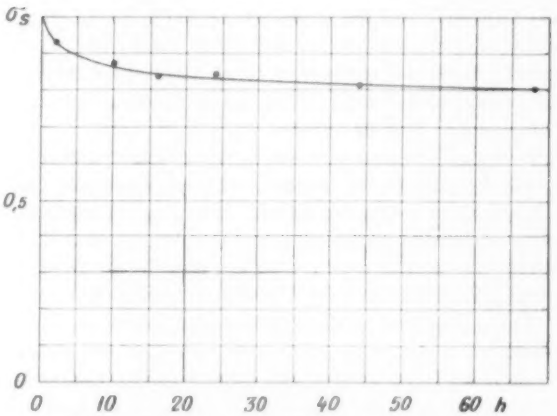

Fig. 8 Stresses after different heating times

Figure 8 shows the results from tests at different heating times in the oven. During the first 10 hr, when the stresses are reduced from 1 to 0.86, the reduction is rapid. Then the time has a small effect, and the stresses approach with a rather asymptotic character the figure 0.80 after about three days' heating. In the latter case the test device was allowed to cool in the oven.

From these results it may be concluded that, with a heating during several days, the remaining stresses will be somewhat lower than indicated for the yield point of the material at the temperature in question.

BIAXIAL STRESSES—RESIDUAL STRESSES

Hitherto I have been dealing with objects having

monoaxial stresses. Such stresses exist in objects which are subjected to external forces in one direction. One must presume that the stresses existing in a welded object are of another type. These stresses do not originate from external forces but are due to forces tied up inwardly, which do not at all manifest themselves outwardly. These internal stresses are different both in size and direction in the object; side by side there are stresses with different signs (positive or negative). At one point there will be stresses in more than one direction; the stresses are no longer monoaxial, as postulated in the above, but will be biaxial or triaxial.

If such multiaxial stresses are at hand, one cannot *a priori* presume that they will be reduced at a heating in the same way, as did the monoaxial stresses. However, should this be the case, there would in such an object with internal stresses be a reduction not only of the high stresses but of all stresses, both small and large. There would be a general stress reduction. This is proved by the following argumentation.

Internal stresses must always be so distributed that they balance each other. This is a basic condition that is easy to understand. Should there be, somewhere in the object, a stress near the yield point of the material, this stress would be reduced at heating. However, this would interfere with the balance within the material, and the consequence would be a general change in stresses, stress reduction within the whole range. Even comparatively small stresses—far below the yield point corresponding to the heating temperature—would thus be reduced.

How will this theory stand when confronted with reality? The above experiments by Forsman and Olsson[1] are excellent examples. Here the tested objects are real, welded workpieces, and it is known that these specimens really have the stresses, and the distribution of stresses, which are likely to exist in welded objects.

These scientists carried out tests on specimens, which consisted of plates of mild carbon steel of the dimensions 700 x 700 x 30 mm with a hand-welded double V-weld in the middle. On these plates were marked out measuring points on either sides in a checkered pattern and with the division 60 mm across and along the weld. These gage lengths of 60 mm were carefully measured. Then the plate was heated to 200, 300 and 550° C, respectively, with full heat during at least 12 hr. Afterward the gage length was measured again. Two such plates were examined.

I have compiled Forsman and Olsson's results in Fig. 9. The temperature is marked out as the x-axis and the changes in measurement in μ as ordinates to the left. The changes in measurement along the welding direction were contractions and across the direction, extensions. Both these manifestations are marked out downwardly in Fig. 9. Naturally, the stresses are very variable in such a specimen. Even within the comparatively long gage length of 60 mm, considerable variations in stress are likely to exist. These circumstances have also been pointed out and established by Forsman and Olsson. However, if a mean value is

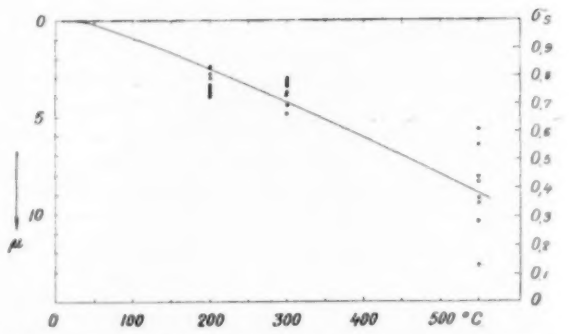

Fig. 9 The stress relief according to Forsman and Olsson

deduced out of a series of figures one will get a statistical result that says a great deal. I have chosen to use the mean values instead of the measured values proper, which were so many that the whole thing would have been unclear. In Fig. 9, e.g., one point represents the mean value of the changes in measurement along the weld on one side of one of the plates, another point represents those across the weld on the opposite side, etc. For each test temperature totally eight measuring results were obtained from the two plates.

Forsman and Olsson have assumed that an object with internal stresses, when relieved, e.g., by heating, undergoes a certain change in shape, which is proportional to the size of the relieved stress. In fact, this may be mathematically proved; however, we shall not take this up for the moment.

However, let us suppose this and then cast a glance on Fig. 3, where we find that at 550° C the yield point at room temperature has decreased by 62%. If we venture to suppose that there will be no creep in the material, we could apply this to Forsman and Olsson's results and find that the changes in measurements at 550° C of heating temperature, the mean value of which is 9 μ according to Fig. 9, would be proportional to a stress reduction of 62%. With this figure to start from we can graduate the axis of ordinates according to the right-hand part of Fig. 9 in remaining stresses with the yield point for the steel in question set to 1.

If in this new system of coordinates, where the heating temperature is the abscissas and the remaining stresses are ordinates, we fit in the graph of Fig. 3, we get the graph as drawn in Fig. 9. As will be seen it follows rather well Forsman and Olsson's figures at 200 and 300° C. This result is an indication that the state, which we have found above for monoaxial stresses, would apply also to internal stresses in general and residual stresses in particular. Unfortunately Forsman and Olsson had no opportunity of measuring directly the value of the relieved stresses. The investigations showed the degree of stress relieving at 200 and 300° C in relation to the stress relieving at 550° C, but not the absolute value.

To determine the absolute value of the stress reduction I do not consider the test plate used by Forsman

and Olsson as suitable. One can make such a plate and get a certain, unknown state of stresses, which can be measured and determined, but one cannot weld another such plate and get exactly the same state of stresses as in the former one. The character of the stresses will be the same right enough, but the value and the distribution will vary within too wide limits. For this particular investigation it is absolutely necessary, with now existing methods of stress measuring, to have two or more specimens which have stresses that are quite equal in size, at least in one direction. One may then establish the state of stresses in one of the specimens and submit the others to heat treatment at different temperatures. Afterward the stresses in these specimens are measured and from the differences between these latter stresses and the stresses in the nonheated specimen one may deduce the stress relieving obtained. With the present methods of stress measuring one must entirely or partly spoil the object at measuring, and the specimen may therefore not be used for another measuring, e.g., after heating.

The question is now: How shall I get a welded specimen that has such a form and is of such a nature that I can make more such specimens which all have the same stresses, at least in one direction? Furthermore, it is a condition that the specimen should be like those used in practical life and not merely a construction for laboratory tests.

I picked out such specimens where I was sure to have a certain known stress at least in one direction, namely, the yield point of the weld metal. Such stresses exist in the root of a multirun arc weld in a single-V groove. As testing object I chose all-beveled plates according to Fig. 10, each 150 x 125 x 32 mm, which were welded together with 36 runs in a single-V groove. The workpiece was allowed to cool down between each deposit. To ensure that the plates should be plane after welding they were put at a counter angle of 20 deg before starting the welding, as shown in Fig. 10. The base material was mild carbon steel. When the root bead had been welded, the root was gouged and a backing run was welded, both runs with 3.25 mm electrodes. With this procedure the root would consist of weld metal only in the place where the stresses were measured. Then the groove was filled first with 3.25-mm and then with 5-mm electrodes. The currents were normal, d c with electrode negative.

The contractile force on the groove edges by one run after another will bring the edges nearer together. At the end, the center parts of the weld will, however, act as a moment axis, while the root part tries to counteract with tensile stresses here as a consequence. On account of the large number of runs these root stresses will become very large. One may expect that they will be as great as possible, and, as previously mentioned, they will keep at the yield point of the material. This applies to the stresses across the root. Along the root stresses will mainly form only when the backing run is being welded, and when this has been finished there will be a stress along the backing run which is equal to the yield point of the weld metal. The stress along the backing run will be reduced by the heat when the groove is filled with runs, so that the final result will be stresses across the root equal to the yield point and along the root stresses, the size of which perhaps may be a certain part of the yield point figure, smaller than this.

We should now have obtained a specimen with stresses that are just at the yield point of the material across the root, and we can make an unlimited number of specimens with exactly the same stresses in that direction.

The electrode used was of acid type with $\sigma_{yl} = 43.7$, $\sigma_{yu} = 45.6$ and tensile strength = 48.7 kg/sq mm.

The question is: Which value could the yield point be expected to have in such specimens? To ascertain this, the root of the weld was tested for hardness across the weld, and Fig. 11 shows the result, where the hardness in Brinell number is marked out to the left. By multiplying the Brinell number by 0.36 one gets, as is known, the approximate tensile strength, and this is read off to the left in Fig. 11. We see that outside the weld it is considerably lower than in the weld metal, where the hardness is rather evenly distributed, with a tensile strength of 65 kg/sq mm. Ordinary non-normalized arc-weld metal usually has a yield point

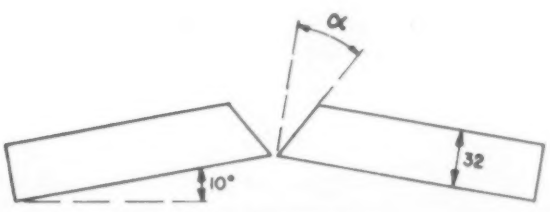

Fig. 10 The test piece

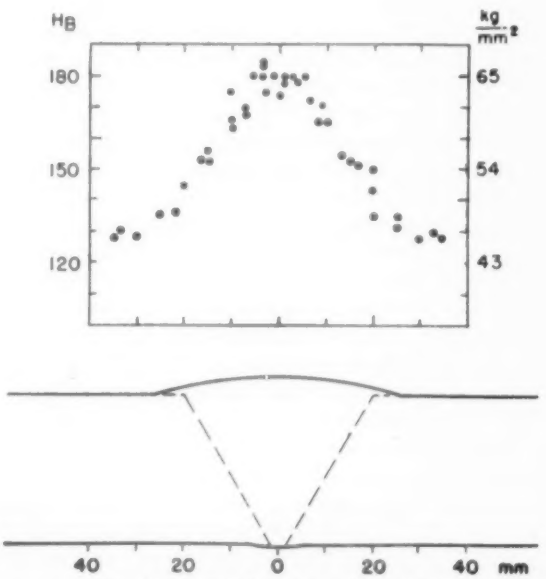

Fig. 11 Brinell hardness of the joint

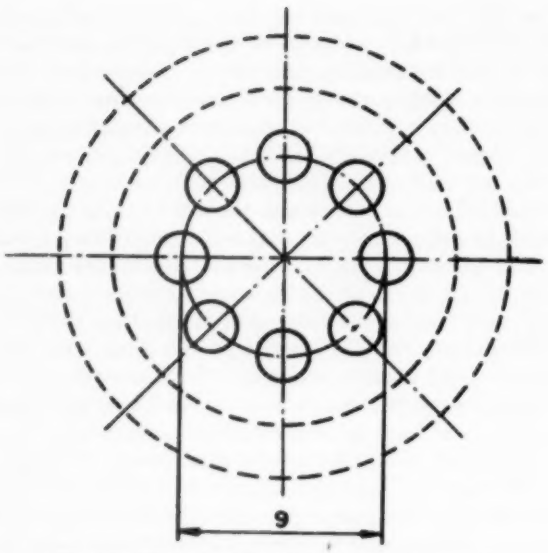

Fig. 12 The principle of the stress measuring

that is 0.8 times the tensile strength. Thus, the yield point in this case should be about 50 kg/sq mm. The stresses across the weld in the root thus should lie somewhere round this figure.

I have previously described a suitable method for gauging residual stresses[4] and will not deal with the principles here except briefly to say that it is the distance between conical holes that is measured, the holes placed according to Fig. 12 in a circle, with a diameter of 9 mm, around the place where the stresses are to be measured. After measuring the distances between diagonal holes in four directions a groove is cut according to the dotted lines in Fig. 12 around the circle of holes to a depth of 6–10 mm. The holes consequently will be situated on a tap, which has been detached from the specimen and relieved from residual stresses by the cutting. Another measuring of the hole distances manifests the changes in measurement, and the residual stresses may be deduced. The measurings are done with a special extensometer, which permits an accuracy of approximately ±0.0005 mm.

Figure 13 shows a polished and etched cross section through the weld after measuring the stresses. The runs appear, and the conical holes and the milling groove around the tap are visible. The stresses were measured in three places in the root of the weld as per Fig. 14.

It must be borne in mind that we have to do with a weld metal of a high valence electrode, and we must not *a priori* presume that the change of yield point of this material at heating is identical with the graph as per Fig. 3.

This is not the case either, and Fig. 15 is a diagram of the value of the yield point at different temperatures for the electrode used at the tests. The values as per the points in the diagram have been available by courtesy of Mr. Norén, Mining Engineer, who has published[5] measuring results also for other electrodes. One

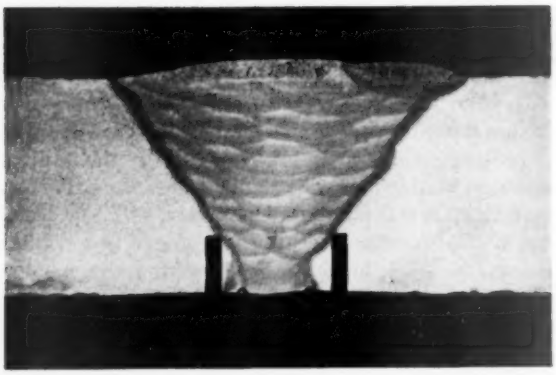

Fig. 13 Section of the weld

is a little astonished when noticing how much the graph differs from the form which we have hitherto been used to seeing as shown in Fig. 3. Thus, there is at 200° C a reduction of the yield point of only approximately 6%, whereas at 300° C we have obtained a reduction of the yield point of approximately 32%, i.e., the same or a little more than according to Fig. 3. The graph in Fig. 15 seems to be typical for weld metal from any electrode.

If the theory of stress relieving outlined in the above is true, there should be expected, in the specimens, a reduction of stresses according to the graph in Fig. 15, because in these specimens the stresses are measured in weld metal only.

According to the method of stress measuring described above one may establish dilatations in four different directions. Of these dilatations one may analytically, as per Hooke's generalized law, calculate the value and direction of the main stresses. For the sake of clearness I have, however, found out a graphic method.

If the dilatations are known in at least three directions, one may deduce the value and direction of the

Fig. 14 Photo of the test piece

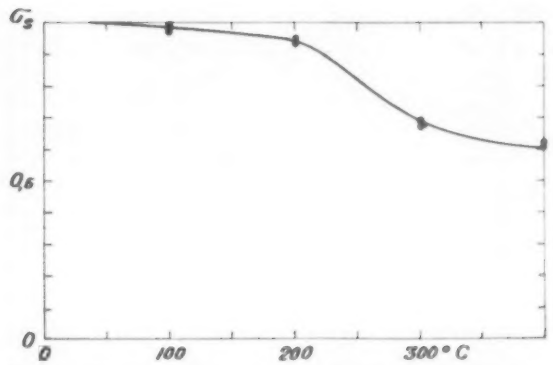

Fig. 15 The yield point of weld metal at different temperatures

main strains as in Fig. 16. Suppose that we have measured the contractions Δ_b Δ_c and Δ_d in the directions square to the weld, $+45°$ and $-45°$, respectively. These strains are marked out after a horizontal line AB as in the figure, viz., the distances AB, AC and AD. At right angles to the line AB are drawn the lines CE and DF, through C and D, where $CE = BD$ and $DF = BC$. The center point on the line EF will be the center of a circle, which passes through the point B.

We will, in the following, use these symbols: Δ_a is the strain on the 9-mm gage length along the weld; Δ_b corresponds to a 90-deg angle; Δ_c and Δ_d are the corresponding measurements on the gage length between the conical holes which are placed at an angle of $+45$ and -45 deg to the welding direction. Of these four quantities, Δ_b, Δ_c and Δ_d are marked out in Fig. 16 along a horizontal line AB, namely the distances AB, AC and AD, respectively. At right angles to this line AB the lines CE and DF are drawn through C and D,

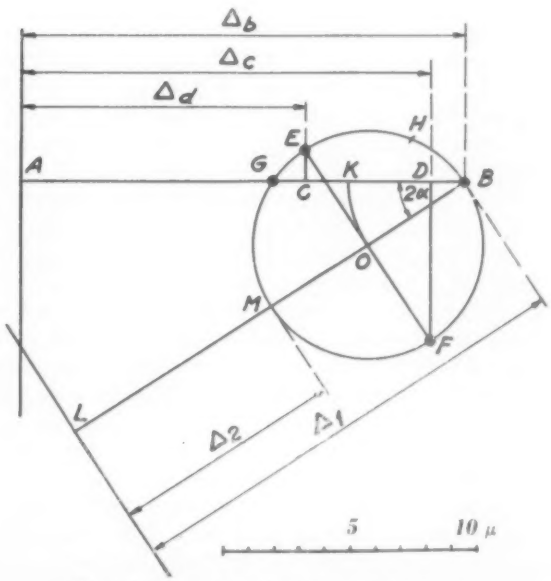

Fig. 16 Way of getting the main stresses

where $CE = BD$ and $DF = BC$. The center point on the line EF will be the center of a circle that passes through the point B. If Δ_a is set off along the line AB, the point G shall fall on the drawn circle, if the measurements are right. This fourth gage length serves, thus, as a check that the right measurement values have been obtained.

The curve BH equals the curve OK. The distance from H to a line square to the line BO, which line intersects the extension of BO in L, equals Δ_b.

With simple geometrical constructions it is now easily confirmed that the distances LB and LM are the main strains Δ_1 and Δ_2 and that the angle 2α gives the angle α, that the main strain $\Delta_2 = KM$ forms to the welding direction. Consequently, the circle constructed is a Mohr's circle.

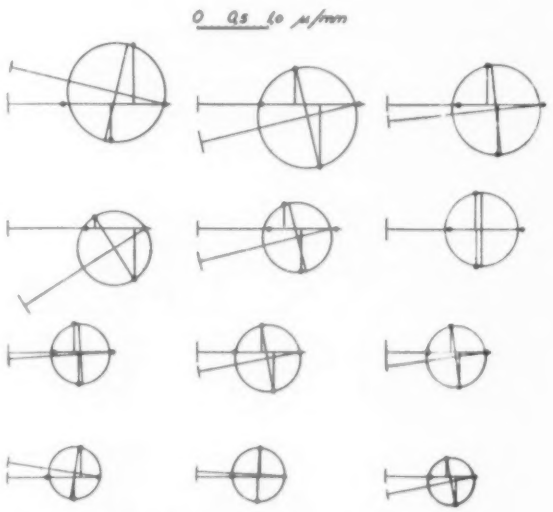

Fig. 17 Getting the main stresses

In Fig. 17 the quantities Δ_1, Δ_2 and 2α are constructed in the way mentioned for all measurements. The values measured are indicated by points, and the circles drawn so that the error in measuring is considered to be of the same size in all four directions.

The top row with three Mohr's circles in Fig. 17 refers to a specimen of the appearance I have described above and which has not been heated. This row is the measured results of the three measuring points on the specimen. Next row of three circles refers to a specimen which had been heated during 16 hr at 190° C and the third row shows the result from a specimen which was heated during 16 hr at 300° C. The bottom row refers to a heating temperature of 350° C.

Out of the values of the main extensions, obtained from Fig. 17, one may deduce the value of the main stresses σ_1 and σ_2 according to Hooke's law, where the modulus of elasticity is set to 20,000 kg/sq mm, and Poisson's constant = 0.3. In this way we know the value and direction of the main stresses, and these are

marked out in Fig. 18 with arrows indicating the value and direction of the main stresses for the mentioned four specimens. The value of the stresses is stated in kilos per sq mm. To the left the heating temperatures 190, 300 and 350 C are indicated.

Of the first-mentioned, nonheated specimen it appears that the yield point lies apparently around the one expected in the above. Several such nonheated specimens have been measured and the stresses were of the same value and distribution as in this particular one. There is some reason to believe that the distribution of stresses in such a specimen would be such that the stresses across the weld would be as great as the yield point of the material permits. We know from the science of elasticity that the stresses in a biaxial state of stresses may rise to 15% above the yield point. The stress square to this thus always should remain at a value of half the aforementioned stress. Consequently, the main stresses should always be of the same value. In spite of the fact that there is no such relation between the main stresses according to the top series in Fig. 18, the main stresses will apparently always be of the same size, which is of great importance to the tests now in question.

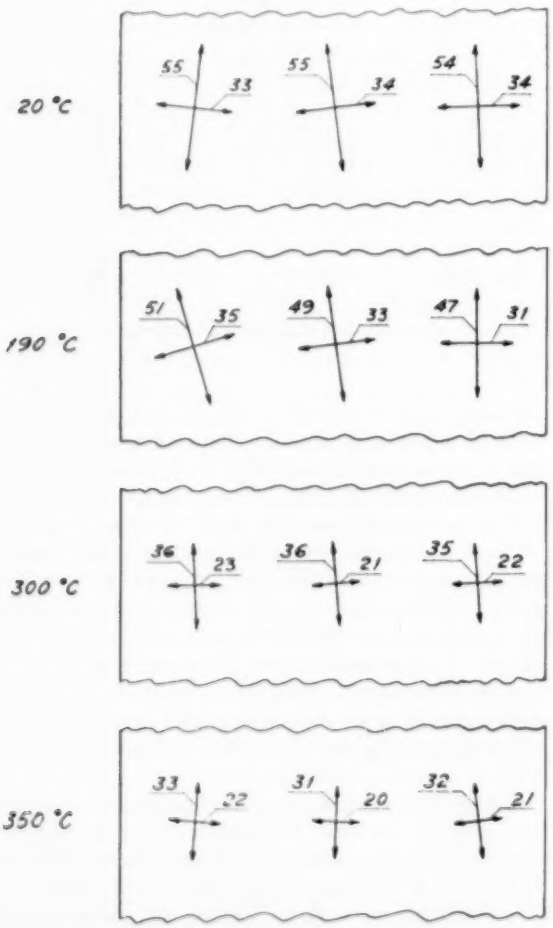

Fig. 18 The main stresses for four test pieces

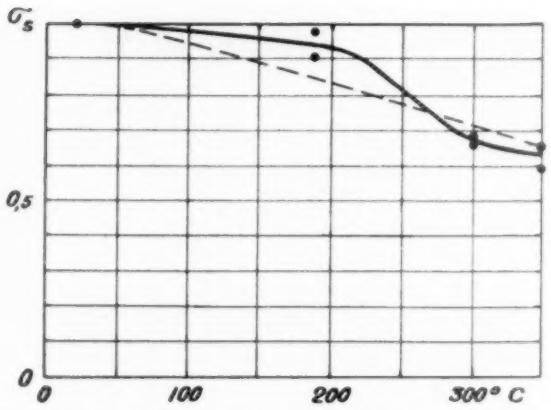

Fig. 19 The residual stresses after heating to different temperatures

If we look at the second test from the top, we see that the stresses along the weld have hardly changed, while the stresses across the weld have been reduced by a few percent. This agrees with the theory above, where, according to Fig. 15, at 190° C one can read off a reduction in stress of only 5%. In the third specimen, which was heated to 300° C, we have reduced the stresses both along and across the weld by approximately 32% or the value foreseen as in Fig. 15. In the fourth specimen the stresses have been reduced somewhat more than in the previous ones, as has been anticipated.

I should like to emphasize that the supposition above has been confirmed, namely, that not only stresses near the yield point of the material at room temperature have been reduced but also lower stresses—the stresses along the weld, which we see from the two lowest tests.

The test results have been compiled in Fig. 19. Each point refers to the average reduction in the main stresses of each specimen when heated to the temperatures as per the x-axis. Between the measuring results the full-line graph is plotted. This graph is the same as the one in Fig. 15, i.e., the graph indicating the reduction of the yield point at heating to a certain temperature. The theory, which we found for the stress relieving at monoaxial stress, will thus apply also to biaxial stresses.

Consequently, one may consider it as verified that Fig. 19 illustrates the highest internal stress that may be present in a construction that has been heated to a temperature according to the x-axis. The full-line graph refers to the weld metal proper and the dotted one to the base metal. The stresses refer to each yield point set to 1. Because the yield point of the weld metal for a normal electrode is approximately twice that of a mild steel parent metal the residual stress in the weld metal will be greater than in the parent metal. From 300° C and upward the weld metal and parent metal run parallel. A heating below 300° C has a minor effect on the internal stresses of the weld metal proper, but at 300° C the stresses are reduced to two-thirds. A further elevation to 350° C does not in-

crease very much the stress reduction; yet another elevation beyond this figure falls outside the bounds of this work. It is possible that when heated to more than 350° C the creep of the material will be effective.

In short, I consider it as verified that a heating to any temperature within the temperature range dealt with, reduces the stresses in the object so that the relation between the value of the stresses in the heat-treated specimen and the stresses in the same before heating is the same as the relation between the yield point of the material at the temperature in question and the yield point of the material at room temperature.

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Initiation and Propagation of Brittle Fracture in Structural Steels

Discussion by Bernhard Persson

The authors of the above paper have referred to M. L. Williams' paper "Investigation of Fractured Steel Plates Removed from Welded Ships," and made the following conclusion from it:

"The stoppage of brittle cracks once in motion requires a notch toughness which may be as high as 52 ft-lb, depending on the steel and probably on the amount of elastic strain energy available at the particular location of the ship."

It seems to the writer that the above judgment has not quite correctly expressed the purport of M. L. Williams' results of investigation as may be evident from the following few remarks.

In M. L. Williams' paper the groups "Thru" and "End," taken together, may be considered as representative of the steel quality used, as the plates included in these groups only by chance happened to be in the way of a crack. In these groups all plates with an impact test energy above 19 ft-lb belong to the group "End." It seems to be permissible to draw the conclusion that plates with impact test energy above 19 ft-lb in practically all cases are able to stop a crack already in motion. It must, however, be observed that this value should be reached at the lowest temperature which the plate may be exposed to in normal service of the ship.

The writer of these lines has tried to illustrate this in another way (see Fig. 1). This figure is made by using the test results included in Fig. 8 of M. L. Williams' paper. The curve *A* shows the distribution of the impact test values of all plates included in the groups "Thru" and "End" taken together which, as already mentioned, represent the average quality of the steel used. The ordinates of the curve are the relative number of plates within a foot-pound interval of 5 units.

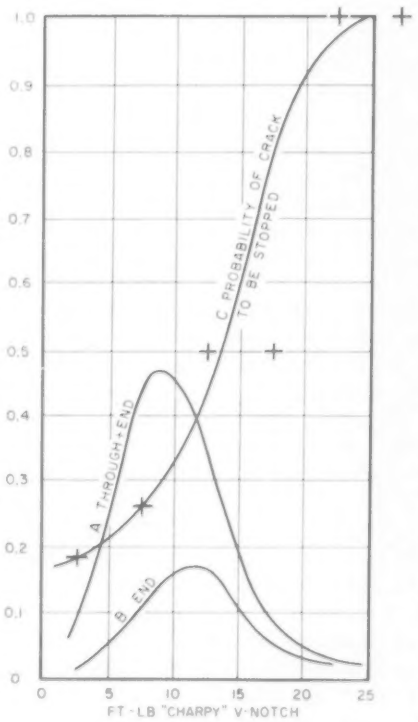

Figure 1

In the same way the curve *B* is made for the plates included in the group "End" only. The curve *C* shows the quotient *B*/*A* which may be considered as the probability of a crack to be stopped. As will be seen this probability reaches the value 1 at an impact energy of about 20 to 25 ft-lb.

Bernhard Persson is connected with the Eriksbergs Mek. Verkstads Aktiebolag, Gothenburg, Sweden.

Paper by Peter P. Puzak, Earl W. Eschbacher and William S. Pellini was published in THE WELDING JOURNAL, 31 (12), Research Suppl., 561-s to 581-s (1952).

Authors' Reply

The authors appreciate Mr. Persson's concern with respect to the statement that Charpy V energies as high as 52 ft-lb may be required to stop a crack once in motion. The possibility that such high energy absorptions may be required is certainly most disturbing to anyone connected with ship structure design. It is agreed that Dr. Williams' work shows this to be the exception rather than the rule and this fact was also demonstrated by the crack starter tests data reported by the authors. However, at this early stage of developing generalizations concerning Charpy V energy correlations with service, it is essential to recognize the extremes even though of low probability. The statement is correct as presented, inasmuch as the brittle fracture traveled halfway across the 52 ft-lb plate (56B of Williams' report) before changing to shear and stopping; this was not a case of the fracture barely entering the plate and then stopping. The air and water temperatures were reported as 56 and 58° F, respectively. Inasmuch as this plate developed approximately 43 ft-lb at 40° F and 30 ft-lb at 20° F, it appears that a reasonable error in reporting the fracture temperature would not greatly lower the reported energy values. This plate is also of interest in that it was the last plate of a major fracture and, therefore, was subjected to limiting overloading conditions, which fits the concepts advanced by the authors that such behavior is allied to the stress conditions associated with the fracture. Another example of a halfway brittle fracture, and exception to the 19 ft-lb generalization, was provided by a plate of 42 ft-lb at the fracture temperature of 67° F (55B of Williams' report).

It appears that there is no basic disagreement in the interpretations of the ship fracture data by the discussor and the authors, for Mr. Persson states that "plates with impact test energy above 19 ft-lb in practically all cases are able to stop a crack already in motion." The word "practically" is essential to this statement in the views of both parties concerned.

The Cylinder Specimen for Testing the Cracking Tendency of Steels and Electrodes

by Paul Werthebach

THE cylinder specimen in Fig. 1 consists of two 2-in. rounds 2 in. long welded together at the highest recommended current with three beads in rapid succession on one side. The specimen then is turned over and the test bead is deposited on the other side. Only $^5/_{32}$-in. electrodes are used. The surface of the test bead is examined for cracks, crater cracks being disregarded. If the total length of the crack or cracks does not exceed 1 in., cracking is said to be moderate. Over 1 in. of cracking is called severe.

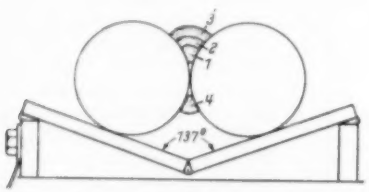

Fig. 1 Setup for welding the cylinder specimen

The cylinder specimen in slightly different form was adopted as tentative standard by the Technical Committee of the German Welding Society in February 1951 for testing the tendency of austenitic electrodes to crack in welding high-tensile steels (71,000 to 85,000 psi tensile strength). In the standard test there are only two layers on the first side, and the bars are clamped together during the test to prevent them spreading apart before the test bead is deposited. The test was developed by Kurt Kautz, and was the outgrowth of difficulties in welding nonaustenitic steels with austenitic electrodes (German Patent DRP 567,094, Oct. 5, 1930).

In the present research 7 steels and 25 electrodes were tested, Tables 1 and 2. Three layers on the first side made the test more severe than two layers. Cracking was more severe when the test bead was deposited at high currents (180 amp, for example) than at low currents (150 amp). Since at high currents only half as much electrode could be deposited as at low currents, the beads were thinner. The contour of the beads was not studied.

Most of the electrodes produced cracked porous welds on the high-sulfur steel 9S 20. Only six electrodes produced sound welds: the bare, two 6020, two lime basic, and the oxidizing electrodes. The sulfur contents of the test beads were 0.065% for the bare, 0.069% for the 6020 and 0.091% for the oxidizing electrode.

Table 1—Composition of the Steels

	C	*Si*	*Mn*	*P*	*S*	*Cu*	N_2
9S 20	0.04	0.00	0.65	0.054	0.245	0.09	0.016
St 37	0.08	0.00	0.36	0.017	0.032	0.17	0.005
St 52	0.19	0.52	1.12	0.020	0.030	0.19	0.005
C 25	0.26	0.24	0.62	0.018	0.033	0.18	0.006
C 35	0.34	0.19	0.69	0.045	0.034	0.20	0.006
C 45	0.45	0.21	0.69	0.033	0.032	0.16	0.007
C 67	0.71	0.20	0.70	0.027	0.028	0.15	0.006

Table 2—Electrodes Used in the Tests

Number of brands	*Coating thickness*	*Coating factor**	*Type of coating*
2	Bare	1.00	Bare or cored
2	Thin	1.12–1.16	Arc stabilizing
7	Medium to thick	1.30–1.47	Rutile, 6012–13
6	Thick	1.58–1.63	6020
1	Thick	1.60	6013
1	Thick	1.60	Oxidizing
3	Thick	1.55–1.63	Low hydrogen, lime basic
3	Medium to thick	1.33–1.51	Austenitic

* Ratio of outside diameter of coating to diameter of core rod.

On the mild steel St 37 the only electrode to crack was an old-style austenitic type. All the austenitic electrodes cracked on St 52, although only one other electrode failed, a 6020. On the higher-carbon steels C 25 to 67 the austenitic electrodes also cracked badly. The bare electrode was free from cracking on C 25 and C 35 but showed moderate cracking on C 45 and C 67. The cored electrode cracked badly on C 45 and C 67, and cracked moderately on C 35. One of the thin-coated electrodes cracked badly on the four higher-carbon steels, while the other cracked only on C 67 and then only moderately.

The 6012 electrodes were satisfactory on C 25 but cracked more or less seriously on C 35 and C 45. All cracked on C 67. Likewise all 6020 electrodes cracked badly on C 67, and most of them cracked badly even on C 35 and C 45. Nearly all cracked to some extent on C 25. The heavily coated 6013 electrode cracked moderately on C 25 to 45 and badly on C 67. The oxidizing and lime basic electrodes did not crack on C 25 and 35, showed moderate cracking on C 45 and cracked badly on C 67.

Analysis of the test beads showed that most contained 0.08 to 0.13% carbon on C 25, 0.15 to 0.22% carbon on C 35 and 45, and 0.27 to 0.35% carbon on C 67. The only exceptions were the beads from the bare and oxidizing electrodes, which contained 0.05% carbon or less.

The cylinder specimen is superior to the double fillet weld crack specimen in being less sensitive to small variations in fit up. It is also a valuable plant test. However, the cylinder specimen is not wholly satisfactory as a specification test because testing must be supervised rigidly to avoid operator influence.

Abstract of Die Prüfung von Schweisszusatzwerkstoffen und von Stählen auf Neigung zur Schweissnahtrissigkeit," published in *Stahl u Eisen*, **73**, 84–91 (1953). (Abstracted by Dr. G. E. Claussen.)

The Hydrostatic and Hammer Tests Applied to Pressure Vessels

An abstract of a survey made by the Inspection and Testing Subcommittee, Fabrication Division, Pressure Vessel Research Committee, of the hydrostatic and hammer tests as now required by the ASME Boiler Construction Code

A STATEMENT OF THE PROBLEM

"AT THE present time it is required practice to hydrostatically test all types of unfired welded pressure vessels. There are two types of pressure vessels recognized: (1) those which have been stress relieved and radiographed and (2) those which have not. The vessels which fall under the first class are hydrostatically tested to not less than twice* the maximum allowable working pressure for a sufficient time to permit an inspection of all joints and connections. Those vessels which fall in the second category, when they are 12 ft or less in diameter and/or 20 ft or less in vertical height are tested to a hydrostatic test pressure of $1^1/_2$† times the maximum allowable working pressure and while subjected to this pressure the welded joints are given a thorough hammer or impact test. The impact test consists of striking the plate at 6-in. intervals on both sides of the welded joints and for the full length of all welded joints. The weight of the hammer in pounds is approximately equal to the thickness of the shell in tenths of an inch but not to exceed 10 lb and the plates are struck with a sharp swinging blow. The edges of the hammer are rounded to lessen the chance of defacing the plates. The same hammer test is applied to vessels over 12 ft in diameter and/or 20 ft or more in vertical height while they are empty and at atmospheric pressure. Following the hammer test the vessels are hydrostatically tested to not less than twice* the maximum allowable working pressure for a sufficient length of time to permit inspection of all joints and connections.

"While this general practice has been used to determine the suitability of pressure vessels for service, there is some question as to the effectiveness of these tests in showing up the defects in the manufacture of the pressure vessels as far as the welding flaws or faulty material is concerned, and to what extent, if any, these test procedures may damage a vessel with respect to its strength for future use. Also, the important factor of the effect of temperature in the failure of pressure vessels is not included (primarily low temperature) nor does it indicate a degree of safety for the vessel if it is subjected to repeated pressure cycling in use." (Dr. C. O. Dohrenwend, Rensselaer Polytechnic Institute, Feb. 22, 1949.)

SURVEYS CONDUCTED BY THE PVRC

As a preliminary step in evaluating the effectiveness of the hydrostatic and hammer tests for pressure vessels, the Inspection and Testing Division has sponsored two comprehensive surveys.

The first survey was intended to obtain accurate *data on flaws which manifest themselves during shop tests* on newly constructed vessels. The second survey was an endeavor to obtain a cross section of opinion of the Shop Inspectors directly responsible for administration of the rules as to the effectiveness of the requirements for hydrostatic and hammer testing as now set forth in the ASME Boiler Construction Code.

Both surveys were conducted with the cooperation of the following ten inspecting agencies: Boston Mutual Boiler Insurance Co.; California (State) Division of Industrial Safety; Fidelity and Casualty Company of New York; Hartford Steam Boiler Inspection and Insurance Co.; Lumbermens Mutual Casualty Co.; Maryland Casualty Co.; Ocean Accident and Guarantee Corp., Ltd.; Oregon (State) Bureau of Labor; Royal Indemnity Co.; and Travelers Indemnity Co. These organizations gathered the required data and made them available to the Committee, together with other needed information.

Copy of the complete report available on request to Secretary, PVRC.

* This is now "$1^1/_2$ times."

† This is now "$1^1/_4$ times."

Survey of the Flaws Which Manifest Themselves During Shop Hydrostatic and Hammer Tests of New Vessels

Summarizing this information briefly, it is indicated that slightly more than 160,000 pressure vessel tests were reported. Of these, in a little over 4000 tests, noticeable defects were reported as being found by the hydrostatic test, and 30 crack failures occurred under the hammer test. Of the 4000 defective vessels discovered by the hydrostatic test, only 21 cases could be termed as "serious," the others were mostly "pinhole" leaks. Of the 30 hammer test failures, only 9 were serious.

The 21 more "serious" defects manifested under the hydrostatic test included six failures in couplings, faulty material; one laminated head plate; two carbon steel to stainless, heavy to light sections; two cracks at nozzle connection; one crack across weld, shrinkage; two in plate adjacent to weld; one end blew off; one crack in weld joining stays to flat head; one crack in stainless clad seam; cracks in head flange perpendicular to weld.

The nine defects listed as having occurred during hammer test included one 6-in. crack in longitudinal seam of a stainless steel vessel; one 2 in. crack in girth joint, slag dislodged by hammering, crack followed undercut; one 7-in. crack in automatic weld joining a heavy section to a light section; two cracks in girth joints due to automatic electrode "wandering"; one 24-in. crack in longitudinal seam, submerged arc, copper backed, a slag inclusion; one 7-in. transverse crack across head to shell seam; one 4-in. crack in weld at reinforcing pad around welding neck; one defective plate, leakage due to inclusion.*

* Editor's Note: The following excerpt from a recent letter addressed to the Secretary, PVRC, by one of Great Britain's leading manufacturers of pressure vessels, is noted with interest:

"The following information from Mr. Thompson's letter may be of interest to the Testing and Inspection Division. Speaking of the Hydrostatic Hammer Test he says that we in our own shops have never had any seam faults whatsoever disclosed by this test, which is carried out at 1½ times the working pressure plus 50 psi, or in some cases at twice the working pressure. This experience covers several thousand vessels. He also says that he has not heard of any other Class I manufacturer in Great Britain who has experienced failure under this test."

CONCLUSIONS AND RECOMMENDATIONS

1. The primary purpose of the Hydrostatic Test as a medium of inspection is to determine the soundness of the construction for purposes of acceptance.

2. The Hydrostatic Test, used as a method of inspection, should not be construed as a method for proving the correctness of the design for its intended ultimate service.

3. A proof on the successful use of the Hydrostatic Test as a means of peak-stress-relief, or for any purpose other than the primary function of determining soundness, has never been a requirement under Inspection and Testing practices. If the Hydrostatic Test is to be considered for that purpose, a special investigation to determine more exact limitations on its value should be undertaken.

4. As evidenced by the report of the Task Group on flaws which manifest themselves in new pressure vessels during shop hydrostatic tests, it seems clear that enough leaks and defects of fabrication are currently detected by this means to warrant its retention as an inspection method.

5. The Hammer Test, as currently required by the various pressure vessel codes, is rather loosely defined and hence incapable of proper evaluation.

6. The opinions reported on the Hammer Test represent a wide divergence of thought and no valid conclusions can be reached on the basis of present knowledge. No attempt should be made to exaggerate or de-emphasize its importance.

7. Present knowledge of the Hammer Test can only be extended by a thorough dynamic strain analysis on full-scale pressure vessels under laboratory conditions. Modern techniques and methods now exist which make such a project possible but at a cost which may not be justified since the shop Hammer Test is not expensive to carry out and has not been shown to be harmful. Like other traditional tests its gradual disappearance can be anticipated if it fails to prove its own value.

ERRATA

The authors have called our attention to the following Errata in the paper "The Effect of Strain Rate on Twinning and Brittle Fracture" by D. Rosenthal and C. C. Woolsey, Jr., The Welding Journal, *31* (10), Research Suppl., 475-s to 492-s (1952).

Correct formulas (2), (A1) and (A11) are:

$$\tau_l = \frac{G\gamma_l}{2} \times \frac{l}{L} \qquad (2)$$

$$U_0 = \frac{G}{2}\left(\frac{BB'}{L}\right)^2 V \qquad (A1)$$

$$\tau_l = \frac{G\gamma_l}{2} \times \frac{l}{L} \qquad (A11)$$

The subscript in formula (17) should read "$_0$" and that in formula (A2), "$_s$."

Finally, the value for G on page 489-s should read: 7.92×10^{11} dyne/cm.^{2} Corrected reprints of this paper can be obtained by writing to the Department of Engineering, University of California, Los Angeles.

REX'S WELDER, John Magliocco, uses ANACONDA-997 (Low Fuming) Bronze Welding Rods to repair a cast iron side frame from punch press. The Rex shop braze welds all kinds of industrial machinery—lathes, presses, rollers, gear teeth, ink grinding plates, etc.

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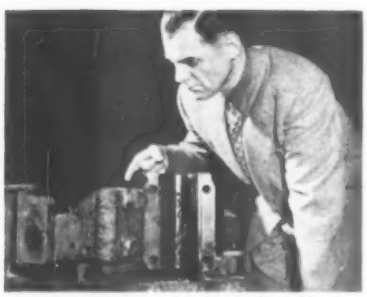
— says Everett Rex, co-owner Rex Auto Radiator & Welding Company, Chicago



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2 STEP RECLAMATION

OF WORN DIESEL ALUMINUM PISTONS

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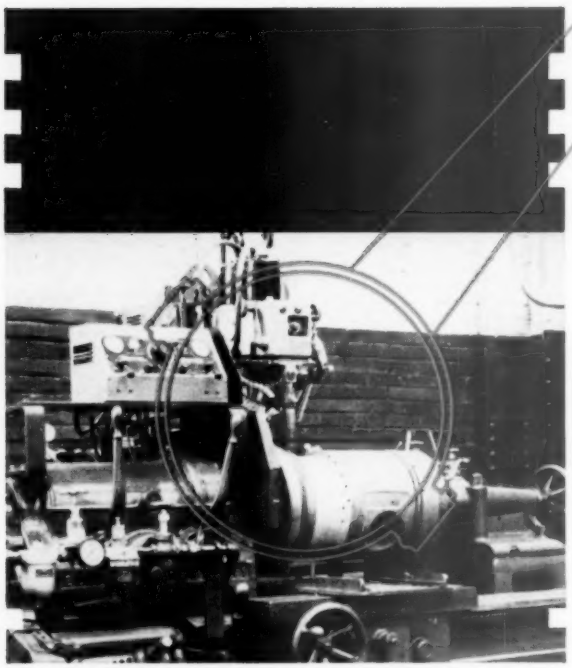

1 AUTOMATIC – The Aircomatic Automatic Head is mounted on a lathe with an auxiliary wire feed to speed the rate of disposition and control heat "input." Both coils supplying the filler metal are consumable electrodes, although only one carries the current. With this unit, the prepared ring groove area is filled in at a rate of 10 lbs. per hour! When the build-up is complete, the reclaimed piston may be machined to original dimensions.

2 MANUAL – Here an operator repairs cracked pistons with the inert-gas-shielded arc gun—the manual version of the Aircomatic Process. No flux . . . no slag removal required. Good visibility combined with the versatility of all-position welding gives you complete control of the welding puddle for delicate repair work.

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